**University of Alberta**

# Muscle Deoxygenation as a Determinant of Static Back Muscle Endurance

By

Geetanjali Kashyap

A thesis submitted to the Faculty of Graduate studies and Research in partial fulfillment of the requirements for the degree of Master of Science

Department of Physical Therapy

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**Dedication to:**

***My Mom and Dad***

For all of their unconditional love, affection, guidance and support to this day and forever. They have inspired thorough me through every step of this work

***Pat and Donn***

For your wonderful and timely help, love, support in my hard time. This work is a result of your affection, constant encouragement and guidance. Thank you for enlightening me with the journey of faith in the Lord

***My friends***
***(Arun, Sirinda, Sandip, Tarun, Laxmi and Shekhar)***

For being my pillar of strength and faith through out these two years. Thanks to you all.

***My Grand parents and family***

For their prayers and blessings throughout all the way through

# ABSTRACT

This study examined the relationships between absolute holding time on the Sorensen test and six physiological variables that might be implicated in muscle fatigue: initial magnitude and rate of deoxygenation, change in tissue oxygenation and blood volume from baseline to test termination and magnitude of initial drop in blood volume and maximum increase in blood volume following the initial drop from baseline. Subjects were 36 normal healthy males, without low back pain, completed one test session during which oxygenation and blood volume trends of the right erector spinae muscle were measured using Near Infrared Spectroscopy.

This is the first study that has analyzed muscle deoxygenation and blood volume changes during maximum voluntary isometric contraction in Sorensen test performance. The majority of the subjects (n=27) demonstrated a decline in the level of tissue oxygenation at the start of the test, which was accompanied by an initial decline followed by an increase in the blood volume to the statically contracting muscle. However, low pearson's correlation coefficients (r=0.005-0.09) revealed changes in tissue oxygenation and blood volume (measured by NIRS) to be poor determinants of absolute holding time on the Sorensen test. Increasing skin fold thickness resulted in greater magnitude of initial deoxygenation and lesser holding time. This study raises questions about the role of muscle fatigue in Sorensen test performance.

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# CHAPTER ONE

## 1 Introduction

Low back pain (LBP) and associated disability are widespread problems in the adult population and industrial workforce (Thorbjornsson et al., 2000, Hultman et al., 1993, Marriott et al., 1998, Willeke et al., 1997, Peterson et al., 2000, Deyo, 1998). A study among a healthy population of Danish adults over a one-year follow-up revealed a lifetime prevalence of LBP in 68-70% of men and 81% of women with 11% suffering from a first-time attack over a one-year follow-up (Biering-Sorensen, 1984). Feldman et al (1999) estimated 18-30 % of adolescents to have LBP. Despite the prevalence and impact of LBP, there has been limited knowledge about its cause , treatment and prevention (Peterson et al., 2000). Prevention has been hindered by limited knowledge of clear, strong risk factors on which intervention strategies can be based (Peterson et al., 1998, Feldman et al., 1999, Deyo et al., 1998 and Hultman et al., 1993). Many physical capacities have been studied as possible determinants of LBP and static back muscle endurance (SBME) is among the few which has been clearly related to this problem (Biering-Sorensen, 1984, Hultman et al., 1993, Luoto et al., 1995 and Nicolaisen et al., 1985). Activity level of the subject, age, body mass index, gender, muscle cross-sectional area, smoking, obesity and familial influences have been studied as possible determinants of SBME (Holmstrom et al., 1992, Mofforoid et al., 1994,

Kankaanpaa et al., 1998, Latikka et al., 1995, Jorgensen et al., 1986, Mannion et al., 1998 and Gibbons et al., 1997), yet there is limited knowledge about this physical capacity.

Near Infrared Spectroscopy (NIRS) has been successfully used on the back muscles to detect localized fatigue in the back extensors during isometric contractions of the erector spinae (McGill et al., 2000, Jensen et al., 1999 and Maikala et al 2000). NIRS measures the relative trend in tissue oxygenation and blood volume continuously and non invasively. As the oxygen consumption continues, monitoring the change in tissue absorbency at 760 and 850nm helps to determine the relative change in tissue oxygenation (Costes et al., 1996 and Bhambhani et al., 1998). Restriction of blood flow and tissue deoxygenation are reported as important factors in the development of muscular fatigue (Yoshitake et al., 2001 and Murthy et al., 1999). An isometric contraction is suggested to be governed by alactic aerobic (ATP-PC system) and anaerobic (glycolysis) energy systems (Sherwood L, 1994). The body utilizes ATP initially then depends on glycogen that results in the accumulation of lactic acid. Hence, NIRS is an ideal and noninvasive measurement tool to determine localized physiologic fatigue of the erector spinae.

This study aims to examine 'physiologic fatigue', indicated through tissue deoxygenation and blood volume changes, as measured by NIRS, as a determinant of SBME

among healthy male subjects. More specifically, this work will determine the degree of association between tissue deoxygenation and blood volume changes and absolute holding time on the Sorensen test of SBME. This is the first study that has investigated changes related to maximum voluntary contraction during Sorensen test performance. All other work has been limited to a percentage of maximum voluntary contraction for a specified time interval.

# CHAPTER TWO

## 2 Literature Review

### 2.1 Clinical Relevance of Static Back Muscle Endurance

Endurance is defined as fatigue resistance to continuous or repeated maximal effort (Mayer et al., 1994). It is also the ability to produce work over time and sustain effort (Ito et al., 1996). SBME is an important functional capacity of the back musculature, and is a feature in many tasks that demand fixed and constrained postures (Jorgensen et al., 1986). Several studies have suggested low SBME to be a risk factor for future back problems (Biering-Sorensen, 1984, Jorgensen et al., 1986, Nicolaisen et al., 1985, Luoto et al., 1995, Kankaanpaa et al., 1998 and Kahanovitz et al., 1987), including the first time occurrence of LBP (Biering-Sorensen, 1984, Nicolaisen et al., 1985 and Luoto et al., 1995). It has been suggested that low SBME is associated with recurrent and prolonged back pain, as well (Chok et al., 1999 and Gundewall et al., 1993). Hultman and Holmstrom et al (1993, 1992) observed people with chronic LBP to have poor trunk muscle endurance capacity and trunk extensor training has been used in exercise protocols to improve back muscle endurance in these patients (Chok et al., 1993). Endurance training of the trunk extensors has been found to be effective in relieving LBP at a 3-week follow-up in patients with subacute low back pain

(Chok et al., 1999), but an effect was not seen in a later follow-up (at the end of 6 weeks) in those who underwent training as compared to those who did not.

**2.2 Sorensen Test (1984)**

SBME received much attention following a study by Finn Biering-Sorensen published in 1984. He investigated a variety of physical measurements as risk indicators for first episodes of LBP among a population of Danish men and women, over a one-year follow-up. SBME, among other physical measures, was investigated as a predictor for the first time occurrence of LBP. The test measured the time for which a subject maintained the neutral alignment of the extended, unsupported trunk (from the upper border of the iliac crest) in a horizontal prone position. The test was terminated when the subject elected to stop due to discomfort or pain or when a holding time of four minutes was reached. Three wide canvas straps secured the buttocks, legs and the ankles. The arms were positioned across the chest during trunk extension.

The test for measuring SBME has commonly been referred to as the "Sorensen test" (Kankaanpaa et al., 1998, Mofforoid et al., 1994, Luoto et al., 1994, Hultman et al., 1993 and Chok et al., 1999). It has been used both as an outcome measure of physical performance in LBP patients (Simmonds et al., 1998 and Novy et al., 1990) and as a first

time predictor of LBP (Jorgensen et al., 1986, Nicolaisen et al., 1985, Luoto et al., 1995 and Kankaanpaa et al., 1998).

**2.3 Measurement of Static Back Muscle Endurance using the Sorensen Test**

A few investigators have conducted the test as per the protocol described by Sorensen (1984), (Holmstrom et al., 1992, Latimer et al., 1999 and Jorgensen et al., 1986) while others have modified it in terms of the:

-Starting position (Gibbons et al., 1997, Latikka et al., 1995, Mannion et al., 1998, Kankaanpaa et al., 1998, Novy et al., 1999, Simmonds et al., 1995, Ito et al., 1996, Luoto et al., 1996, and Mayer et al., 1995),

-Support provided to the lower limb (Sorensen, 1984, Kankaanpaa et al., 1998, Chok et al., 1999, Gibbons et al., 1997, Latikka et al., 1995, Novy et al., 1999, Simmonds et al., 1998, Nicolaisen et al., 1985 and Luoto et al., 1995),.

-Measurement of maintenance of trunk alignment (Mofforoid et al., 1994, Holmstrom et al., 1992, Chok et al., 1999 and Kankaanpaa et al., 1998), and

-Termination criteria (Gibbons et al., 1997, Kankaanpaa et al., 1998, Nicolaisen et al., 1986, Nicolaisen et al., 1985, Luoto et al., 1995, Mannion et al., 1998, Mofforoid et al., 1994, Chok et al., 1999 and Latimer et al., 1999).

### 2.3.1 Starting Position

Variations in the starting position include placement of hands behind the neck (Gibbons et al., 1997, Latikka et al., 1995 and Mannion et al., 1998) and by the side of the trunk (Kankaanpaa et al., 1998, Novy et al., 1999, Simmonds et al., 1998, Luoto et al., 1995 and Ito et al., 1996). Ito et al (1996) varied the starting position by having the subject lie prone on the floor with hands beside the trunk and a pillow under the abdomen. The subject performed trunk extension with maximum cervical flexion and gluteal contraction to maintain the pelvic alignment. Another variation relates to the angle of trunk alignment at the start of the test. Variations include a resting position with the chest wall inclined at 45 degrees from the horizontal prior to the start of the test (Kankaanpaa et al., 1998) or the use of a bench inclined at 6 degrees (Holmstrom et al., 1992).

In 1995, Mayer et al. modified the Sorensen test to measure SBME using a Roman chair device with pelvic, calf and handlebars for patient support. The subject's trunk was flexed to 90 degrees from the waist down, with hands crossed on the chest.

### 2.3.2 Support provided to the lower limb

Biering-Sorensen (1984) provided support to the lower limb at three positions-buttocks, knees and ankles. Variations include the number of straps and their placement. Four

straps at the buttocks, thighs, knee creases and the calves have been used (Kankaanpaa et al., 1998 and Chok et al., 1999). Lower limb support has been modified to include the use of two straps at the calves and ankles (Gibbons et al., 1997 and Latikka et al., 1995) and on the thighs and the calves (Novy et al., 1999, Simmonds et al., 1998 and Nicolaisen et al., 1985). There has been only a single strap used at the distal leg (Kankaanpaa et al., 1998 and Luoto et al., 1995) and the use of no straps has also been reported (Ito et al., 1998).

### 2.3.3 Measurement of trunk alignment

The test protocol used by Sorensen (1984) instructed the subject to extend the trunk and maintain the extended position until he had reached his limit for tolerance of symptoms of fatigue, or to a maximum of 240 seconds. Since then a couple of devices have been used for measuring maintenance of trunk alignment including angle inclinometers (Mofforoid et al., 1994), photocells (Holmstrom et al., 1992) and a B- tracker multiaxial goniometer (Chok et al., 1999). Kankaanpaa et al (1998) used a sac hanging from the ceiling touching the interscapular area as a reference point for horizontal trunk alignment.

### 2.3.4 Termination Criteria

Biering-Sorensen (1984) terminated the test at a subject's maximum limit for tolerance of symptoms of fatigue or when a limit of 240 seconds was reached. Many have followed this criterion (Gibbons et al., 1997, Kankaanpaa et al., 1998, Nicolaisen et al., 1986, Luoto et al., 1995 and Nicolaisen et al., 1985). Variations include termination of the test when subjects reach maximal fatigue without inclusion of a limit for maximal holding time (Kankaanpaa et al., 1998, Holmstrom et al., 1992 and Mannion et al., 1998). Ito et al. (1996) maintained five minutes as the maximum holding time for trunk extension in their study. The test has also been terminated if the trunk deviation exceeded 5 or 6 degrees from the horizontal trunk alignment (Mofforid et al., 1994, Chok et al., 1999 and Latimer et al., 1999).

## 2.4 Reliability of the Sorensen Test

The reliability of the Sorensen test has been determined in numerous studies and in a variety of populations (Simmonds et al., 1998, Holmstrom et al., 1992, Jorgensen et al., 1987, Moreland et al., 1997, Latimer et al., 1999, Mofforoid et al., 1994, Ito et al., 1996 and Mayer et al., 1995, Dedering et al., 2000). High test-retest (same day) reliability (ICC>0.91) was reported for subjects with LBP, and somewhat lesser reliability in a

group without LBP (ICC>0.73) (Simmonds et al., 1998). High inter-day reliability scores were reported for subjects with LBP (ICC=0.88) (Simmonds et al., 1998) whereas moderately high test-retest reliability coefficients ranged from 0.68-0.91 in healthy participants (Simmonds et al., 1998, Holmstrom et al., 1992 and Jorgensen et al., 1986, Dedering et al., 2000). Similarly, high reliability scores (intra-rater, inter-day) were reported (ICC>0.82) for subjects with chronic back pain (Mofforoid et al., 1994). Ito et al. (1996) reported high test-retest reliability coefficients of (ICC) 0.97 and (ICC) 0.94 for healthy men and women, and (ICC) 0.93 and (ICC) 0.95 for subjects with chronic LBP. Keller et al. (2001) measured inter-day reliability of the Sorensen test among patients with chronic LBP and healthy subjects. According to the ICC, the test was more reliable for patients (ICC= 0.93) than healthy subjects (ICC= 0.80).

Measures of reliability of the Sorensen test however have not always been high. Mayer et al. (1995) reported a low inter-day reliability (ICC) of 0.21 for healthy male subjects. A low inter-rater (3 raters on 3 separate days) reliability score (ICC= 0.59) in normal subjects was reported by Moreland et al (1977). Both studies involved the use of a roman chair device with padded calf and pelvic support for Sorensen test performance that might explain the low reliability relative to that reported in other studies.

High inter-rater reliability coefficients were reported by Simmonds et al. (1998) for

a LBP population and control group (ICC of 0.99) while Latimer et al (1999) reported lower coefficients for subjects with current non-specific LBP (ICC=0.88), subjects with recent previous non-specific LBP ( less then 3 months back) (ICC=0.77) and in subjects with no symptoms (ICC=0.83). Alaranta et al. (1994) observed lower intra-observer (ICC=0.63) and inter-observer (ICC=0.66) reliability in healthy men and women. In this study the same physiotherapist conducted intra-rater observations over a period of one year, and two physiotherapists conducted inter-rater observations over a period of one week.

When the subjects with chronic LBP were classified according to self reported activity levels (active subjects greater than 30 minutes of exercise 3 times a week) active subjects were found to have repeatability coefficients (ICC) of 0.96 and inactive subjects had coefficients of (ICC) 0.39 (Mofforoid et al., 1994). Thus, level of physical activity may influence reliability. In general observation, LBP subjects have a higher test-retest, inter-day, and inter-rater reliability as compared to normal, healthy subjects.

**Reliability and test position**

High reliability (ICC 0.68-0.97) of the Sorensen test with varying hand positions (hands by the side and across the chest) has been reported (Ito et al., 1996, Moffroid et al., 1994, Jorgensen et al., 1986, 1987, Holmstrom et al., 1992, Simmonds et al., 1998). An equal

number of studies support the reliability of the use of either test position (of hands by the side or across the chest) to measure SBME (Jorgensen 1986, Latimer et al., 1999, Holmstorm et al., 1992, Dedering et al., 2000). However, two studies demonstrate low reliability (0.21, 0.59) in similar test positions (Mayer et al., 1995 and Moreland et al., 1997).

**2.5 Validity of the test**

Mayer et al (1995) stated, " The isometric Sorensen test has been virtually the only validated clinical tool for trunk extensor muscle endurance testing". The test has demonstrated **predictive validity** through its ability to predict the first occurrence of LBP in a population without a prior history of back pain (Biering-Sorensen, 1984, Luoto et al., 1995 and Hultman et al., 1993). However, Takala and Juntura (2000) found that the Sorensen test failed to predict future back pain. The test demonstrated **discriminative validity** in discriminating between subjects with and without LBP (Nicolaisen et al., 1985, Hultman et al., 1993, Luoto et al., 1995 and Latimer et al., 1999). It is appreciably able to detect performance differences between LBP patients and control groups (Mayer et al., 1994 and Simmonds et al., 1998). **Face validity** has been demonstrated such that the test expresses the point of maximal fatigue when the contraction can no longer be

maintained. The test has proven to have convergent validity (Simmonds et al., 1998) due to moderate associations with other tests that cause stresses on the spine, such as sit-to-stand and repeated trunk flexion. However, some authors have questioned the validity, since there is no gold standard to which results can be compared (Mofforoid et al., 1994, Takala et al., 2000). Electromyographic (EMG) results of the back muscles have also raised controversy over the Sorensen test being a true representation of static endurance capacity of the back muscle. EMG studies report a decline in the median frequencies of the biceps femoris muscle to be correlated with the holding time on the Sorensen test, suggesting that the test fatigues the hip extensors along with the back extensor muscles (Mofforoid et al., 1994, Kankaanpaa et al., 1998).

**Validity and test position**

Predictive validity has been demonstrated (Biering-Sorensen, 1984, Luoto et al., 1995 and Hultman et al., 1993). The protocols used either three straps, one strap at the ankle or no straps, hands across the chest or beside the trunk and the test terminated when a maximum of 240 seconds was reached or when the neutral alignment of the trunk was not maintained. Discriminative validity of the Sorensen test has been established with protocols using two or three straps, arms across the chest and the position maintained up to maximal fatigue (Nicolaisen et al., 1985 and Latimer et al., 1999).

The protocol in this study positioned the subject's prone with the use of two straps (at the gluteal region and the ankle). The hands were crossed across the chest during trunk extension and the test was terminated when the subject reached maximal fatigue or discomfort or could no longer hold the position. A sac hanging from the ceiling at the interscapular area helped to guide the trunk alignment. Testing with this position has been demonstrated to be reliable (Ito et al., 1996, Moffroid et al., 1994, Simmonds et al., 1998, Holmstrom et al., 1992, Jorgensen et al., 1986, 87) and valid (Biering-Sorensen, 1984, Nicolaisen et al., 1985, Luoto et al., 1995 and Latimer et al., 1999).

**2.6 Determinants of Static Back Muscle Endurance (SBME)**

Considerable variation in the holding time of the Sorensen test (10-423sec) has been reported among a general population sample of men (Latikka et al., 1995). A number of factors have been investigated as possible determinants of this variation including level of physical activity, back muscle morphology, anthropometrics, obesity, gender, smoking, psychological factors and others (Holmstrom et al., 1992, Mofforoid et al., 1994, Gibbons et al., 1997, Kankaanpaa et al., 1998, Jorgensen et al., 1986, Mannion etal.,1998).

### 2.6.1 Activity level of the subject

The scientific literature presents conflicting evidence about the role of activity in SBME. Gibbons et al. (1997) found greater frequency and intensity of exercise in the previous year and more years of work and leisure time activity involving physical loading to be significantly associated with SBME, with work and leisure time activity respectively explaining about 3% and 6% of the variation seen in the holding time. Mofforoid et al (1994) also found active subjects to have a greater holding time than inactive ones (Mofforoid et al., 1994). A significant correlation was also observed between activity during leisure time and SBME in probable LBP cases (Holmstrom et al., 1992). However, Alaranta et al. (1994) reported that muscular performance capacity deteriorated rapidly among blue-collar workers as compared to white-collar workers and physical laborers have a greater SBME.

### 2.6.2 Anthropometric measurements

Variances in holding time among women have been explained by body mass index, with heavier women fatiguing faster than lighter women (Kankaanpaa et al., 1998). Also, upper body weight affects the endurance capacity and subjects with a larger "load" (upper body weight) have a shorter endurance capacity (Jorgensen et al., 1986).

Mannion et al. (1998) suggested biomechanical factors such as the degree of lumbar lordosis to the total back muscle strength (which affects the back extensor lever arm and also the muscle length), may account for some of the variation seen among men and women.

### 2.6.3 Other factors

**i) Gender:** Women have been shown to have greater holding time than men, hence a greater endurance capacity (Kankaanpaa et al., 1998, Mannion et al., 1998, Nicolaisen et al., 1985). This can be explained by women having a greater percentage of muscle cross-sectional area occupied by type I fiber and a two-fold higher type I to type II ratio as compared to men. The percentage of type I fiber in the lumbar area has been found to be significantly correlated to the fatigue observed among men and women during the Sorensen test (Kankaanpaa et al., 1998 and Mannion et al., 1998). Type I fibers have many mitochondria and an extensive blood supply network. They also have many oxygen carrier molecules (Mb) and are fatigue resistant having a high endurance capacity (Plowman, 1997). Nicolaisen and Kurt (1985) observed that at a certain percentage of muscle contraction (60% of MVC), women have a greater endurance capacity than men. They believed that this could be because of greater

hindrance to blood flow in males as compared to females, as males experience a greater load and hence greater intramuscular pressure. Mannion et al (1998) suggested that women have better endurance capacity because of the influence of sex hormones. Postmenopausal women and those after the first two days of a menstrual cycle have low levels of estrogen and progesterone, which through unknown mechanisms may influence the differences observed among men and women during test performance.

**ii) Age:** Variability in holding time has been observed to be affected by age although the findings have not been consistent (Kankaanpaa et al., 1998, Latikka et al., 1995). Younger men fatigue faster than older ones, but this was true among white-collar workers and not among blue-collar workers up to the age of 50 years (Kankaanpaa et al., 1998). Latikka et al. (1995) reported less endurance capacity to be associated with increasing age and body weight, and when these two variables were controlled, increasing height resulted in greater endurance capacity.

**iii) Low back pain (LBP):** Individuals with LBP have decreased endurance capacity (Gibbons et al., 1997, Nicolaisen et al., 1985, Jorgensen et al., 1987, Chok, 1999). Nicolaisen (1985) hypothesized that people with LBP might have a greater proportion of fast twitch fibers making the back more susceptible to greater postural stress that

could lead to a disturbance in muscle coordination resulting in reduction of endurance capacity.

**iv) Smoking:** It has been reported that SBME is not affected by smoking habits of a person. (Holmstrom et al., 1992 and Mofforoid et al., 1994).

**v) Motivation:** It has been suggested that static endurance capacity is strongly affected by a subject's motivation to perform the test to maximal fatigue (Biering-Sorensen 1984, Mofforoid et al., 1994 and Kankaanpaa et al., 1998), but there is no direct evidence for this.

**vi) Obesity:** Mofforoid et al. (1994) did not find obesity to relate to SBME. However, Gibbons et al. (1997) explained 15% of the variation in SBME by percentage of body fat.

**vii) Muscle cross-sectional area:** Gibbons et al. (1997) reported no correlation between cross sectional area of the back muscles and SBME. It was suggested that neurological, psychological or other factors might influence the test performance.

**ix) Genetic influences:** The modest degree of familial aggregation in SBME suggests that genetic influences do not play a major role in this physical capacity unlike some other muscle function tests, such as maximum isokinetic lifting strength (Gibbons et al., 1997)

### 3.0 Near Infrared Spectroscopy (NIRS)

NIRS measures the relative trends in tissue oxygenation and blood volume continuously and noninvasively during any physical activity. It is based on the principle that chromophores (hemoglobin, myoglobin and cytochrome oxidase) absorb light energy from the near infrared region of the light spectrum (700-10000nm). Hemoglobin is the primary absorbing compound and more than 90% of the signal comes from it. Myoglobin has a minor contribution to the NIRS signal (McCully et al., 2000, Mancini et al., 1994, Costes et al., 1996 and Bhambhani et al., 1998). At 760nm hemoglobin and myoglobin absorb light energy primarily in the deoxygenated form, while at 850nm light energy is absorbed in the oxygenated form. As the oxygen consumption continues, variability is seen in the absorption spectra. Hence, by monitoring the change in tissue absorbency at these two wavelengths, the relative change in tissue oxygenation is observed. The sum signal of these two wavelengths provides an index of the relative change in total blood volume. NIRS absorption assesses changes in tissue oxygenation and blood volume at the level of small blood vessels, capillaries, and intracellular sites of oxygen uptake (Mancini et al., 1994).

NIRS has been used to monitor oxygen saturation in isometric contractions of the forearm muscle (Homma et al., 1996, Murthy et al., 1997, Hicks et al., 1999, Deblasi et

al., 1996). NIRS has been demonstrated as a reliable instrument to detect differences in muscle deoxygenation at low levels of muscular contraction (10% of MVC) in the extensor carpi radialis brevis muscle (Murthy et al., 1997). Homma et al. (1996) used NIRS and detected a significant correlation between the rate of increase in total hemoglobin during venous occlusion obtained from NIRS signal and forearm blood flow determined by strain gauge plethysmography. Also there was a significant correlation between oxygen consumption index estimated by NIRS and forearm oxygen consumption determined by an invasive method.

Maikala et al (2000) used NIRS in measuring oxygenation trends of the lower back, including localized fatigue in the back extensors. Oxygenation trends of the lumbar erector spinae oxygenation during prolonged contractions of the back extensors (for 30 seconds at 2%, 5%, 10%, 20% and 30% of MVC with one-minute rest in between) have been studied recently in normoxic and hypoxic conditions (McGill et al., 2000). All levels of contractions were associated with reduction in oxygen saturation. It was suggested that tissue oxygen saturation in the lumbar spinal musculature was reduced even at low levels of isometric contractions (2% of MVC). Physiological responses to submaximal isometric contractions (at 5%, 20%, 40%, 60 and 80% of MVC followed by prolonged trunk extension at 20% of MVC for 3 minutes) were also studied by Jensen et

al (1999). A significant decrease in oxygen saturation was found at 20% of MVC, which corresponds to 30-40 mm of Hg intramuscular pressure. The deoxygenation was not associated with any further reduction in oxygen saturation over time. Following exercise there was a sudden reoxygenation of the muscle.

### 3.1 Reliability of NIRS

The reliability of NIRS in measuring changes in oxygenation was demonstrated during cuff ischemia on the vastus lateralis muscle (Bhambhani et al., 1998) and the biceps brachii muscle (Maikala and Bhambhani., 1999). The ICC's for the tissue absorbency range of the vastus lateralis muscle ranged from 0.88 to 0.99 between sessions and 0.95 to 0.97 within sessions. The correlation coefficients ranged from 0.89 to 0.94 between sessions and 0.98 to 0.99 within sessions for the biceps brachii. The reliability of NIRS specifically in measuring changes in oxygenation of statically contracting back muscle was demonstrated only recently (Maikala et al., 2000). Inter-session reliability of the NIRS measures during maximum voluntary isometric back extension for two minutes in healthy subjects without any constraints during sitting and standing postures were established using pearson's correlation coefficients ($r>0.74$) (Maikala et al. (2000).

### 3.2 Validity of NIRS

The literature provides conflicting evidence about the validity of this tool (Mancini et al., 1994, Costes et al., 1996, Macdonald et al, 1999, Hicks et al, 1999). The validation has been demonstrated by Mancini et al (1994) comparing the level of oxygen saturation in the femoral blood gases when the vastus lateralis was tested. Eighteen subjects were studied to determine:

i) the effect of skin blood flow on changes in 760-800 nm absorption,

ii) the correlation of 760-800 nm absorption with venous oxygen saturation,

iii) the effect of changes in forearm blood flow on 760-800 nm absorption and

iv) the contribution of myoglobin in hemoglobin-myoglobin desaturation.

Mancini et al. (1994) concluded that skin blood flow had a minimal contribution and showed that there was a strong linear correlation between absorption at 760-800 nm and muscle venous oxyhemoglobin ($r=0.92$), thus demonstrating the use of NIRS on human tissue for successfully measuring tissue deoxygenation. Absorption at 760-800 nm was altered by changes in limb perfusion and the contribution by myoglobin was minimal. Hence, NIRS appears to principally measure hemoglobin deoxygenation.

A study on muscle oxygenation using NIRS and femoral venous oxygen saturation showed that muscle oxygen desaturation paralleled femoral venous desaturation during

steady state exercise in hypoxia. However, a similar pattern was not observed in normoxia (Costes et al., 1996). The venous blood was deoxygenated in normal exercising muscle, and there was also an increased metabolic demand and reduced arterial oxygen content that might explain the findings in hypoxia. Therefore, this conclusion with respect to the hypoxic state of the muscle has advanced the use of NIRS to further understand tissue metabolism when oxygen delivery is affected.

Comparison of femoral blood gases and muscle NIRS at the onset of leg kicking exercise resulted in muscle oxygen desaturation in the first minute along with femoral oxygen desaturation. Thereafter, there was a steady rise in muscle oxygen saturation, but the femoral saturation continued to decline at a gradual rate in all three gas breathing conditions (14, 21, 70% of inspired oxygen). Macdonald (1999) concluded the use of NIRS is a valid tool for small muscles only. A possible reason for this finding could be the role of myoglobin desaturation. This questions the validity of NIRS to estimate hemoglobin oxygen desaturation as reflected by direct femoral vein sampling (Macdonald et al., 1999).

A comparison between tissue oxygenation as measured by NIRS and forearm blood flow (measured by doppler ultrasound) during isometric contractions of the forearm was studied (at about 10 and 30% of MVC in normoxia and hypoxia). The NIRS value did not

change in the initial 10% of MVC in normoxia and hypoxia but the deep vein oxygen saturation decreased steadily in normoxia and more so in hypoxia. At 30% of MVC both the variables showed a steady decline but the hypoxic state did not affect the NIRS signal. The signal showed a recovery although the blood flow to the contracting muscle was inadequate because of the marked hyperemia post contraction. This work suggested that NIRS cannot be used to estimate venous blood oxygenation, and its validity in measuring muscle oxygenation should be investigated further (Hicks et al., 1999).

### 3.3 Effects of overlying tissues on NIRS values

The effect of the overlying tissues (skin, subcutaneous fat) in measuring tissue oxygenation cannot be ignored. To my knowledge, fat layer thickness is the main factor that can influence the readings of NIRS and can confound measurements for deoxygenation. The subcutaneous fat layer is low absorbing, high scattering tissue which influences the signal received from the deeper tissue, thus making it more difficult to perceive the signal. It has been reported that there is a 50% decline in the optical density of the signal with a two-fold increase in fat layer. Recently, it has been found that NIRS measures are greatly affected by adipose tissue thickness (Beekvelt et al., 2001). The signal received would be under estimated as the absorption of the signal would increase

with increasing fat thickness. The intensity of light reaching the target tissue would have to be increased in such a case (Yamamoto et al., 1998). Other factors like skin color and pigmentation need a change in light intensity to prevent superficial burns. The preferred intensity varies from between 90-110 nm based on skin color and pigmentation.

### 3.3.1 Physiological basis for the use of NIRS

The back extensor muscles have a high degree of resistance to fatigue during an isometric contraction (Jensen et al., 1999) because of the relatively large area of the muscle occupied by type I fiber (slow twitch high oxidative fiber) (Mannion et al., 1997). The association between endurance capacity and type I fiber is dependent on the percentage of muscle cross sectional area occupied by type I fiber and the size of the individual fiber (Mannion et al., 1997). At the start of isometric muscle contraction there is a sudden deoxygenation, after which the deoxygenation curve plateaus when there is no further reduction in oxygen saturation. Once the contraction terminates reoxygenation occurs, followed by a super saturation in some cases (Jenson et al., 1999 and McGill et al., 2000). There could be two primary reasons for the immediate drop of oxygenation at the start of static back extension. One explanation is compromised capillary blood flow due to increased intra-muscular pressure caused by the contraction, therefore reducing oxygen

delivery to the working muscle (McGill et al., 2000). The exercise intensity at which this phenomenon starts is variable. McGill et al. (2000) reported that deoxygenation starts as low as 2% of MVC, whereas Jensen et al. (1997) reported a value of 20% MVC. Jensen also correlated a value of 20% MVC with 30-40 mm of Hg of intra-muscular pressure. Mannion et al. (1997) reported that the Sorenson test involves the muscles of the back working at 40% of MVC. Yoshitake (2001) suggested the upper body works at 45% MVC, indicating that at the start of an isometric back extension there is reduced blood flow to the working muscles and hence decreased oxygen supply. Another possible explanation suggested was reduced oxygen perfusion and increased oxygen utilization (McGill et al., 2000). The occurrence of a steady state after this drop suggests that the body reaches a homeostatic state where it compensates for the oxygen deficit by an increase in the cardiac output (increase stroke volume and minute volume), heart rate and blood pressure, and thereby decreasing the peripheral vascular resistance as a result of vasodilatation of the arteries in the skeletal muscles (Jensen et al., 1997 and Chaudhari, 1991). This mainly occurs because of the stimulation of beta2 receptors on the blood capillaries due to the adrenalin and vasoconstriction in the splanic circulation (Chaudhari, 1991). Tacchycardia occurs which causes an increase in minute volume of the heart resulting in an increased velocity of blood to the working muscle helping it to maintain

the level of oxygen saturation oxygen level (Chaudhari, 1991). After the activity has terminated there is marked restoration of muscle oxygen saturation that might cross baseline measurements and this is possible due to marked hyperemia that results in an increase in oxygen supply to the back muscles. It has been suggested that tissue deoxygenation during prolonged isometric muscle contraction at low levels plays an important role in the development of muscular fatigue (Murthy et al., 1997).

# CHAPTER THREE

## 4.0 Main objective

This study investigated tissue deoxygenation and blood volume changes as a indicator of physiologic fatigue of the erector spinae muscles as determinants of holding time during the performance of the Sorensen test.

## 5.0 Hypotheses

The following specific hypotheses regarding trunk muscle deoxygenation and blood volume changes during static back extension were tested. The hypotheses aimed to capture the aerobic and anaerobic changes during isometric contraction in the erector spinae muscle:

1) A greater magnitude of initial deoxygenation **(B)*** is associated with lesser endurance capacity as demonstrated by a shorter holding time on the Sorenson test.
2) A faster rate of initial deoxygenation **(C)*** is associated with lesser endurance capacity demonstrated by shorter holding time on the Sorensen test.
3) Magnitude of deoxygenation at test termination **(D)*** from baseline is not associated with holding time on the Sorensen test.
4) A greater magnitude of initial drop in blood volume **(E)*** from baseline is associated

with lesser endurance capacity as demonstrated by shorter holding time on the Sorensen test.

5) A greater maximum increase in blood volume following the initial drop from baseline **(F)*** is associated with greater endurance capacity demonstrated by an longer holding time on the Sorensen test.

6) Magnitude of change in blood volume at test termination **(G)*** from baseline is not associated with holding time on the Sorensen test.

*B, C, D, E, F, and G help in the diagrammatic representation of the independent variables in fig 1a, pg 46.

# CHAPTER FOUR

## 6.0 Methodology

### 6.1 Study design

Study measures were obtained simultaneously on one occasion to examine the correlation between changes in tissue oxygenation and blood volume, as possible physiologic indicators of muscle fatigue, and static endurance capacity of the back extensors.

### 6.2 Subject inclusion criteria

The sample tested was a nonrandom sample of convenience. Healthy male subjects were recruited from a university setting. A sample size calculation yielded an estimate of 38 subjects (appendix A). Subjects were excluded from the study if they had any of the following:

- Cardiovascular disease/ uncontrolled hypertension;

-Neurological disease/ cerebrovascular or peripheral vascular disease;

-A history of back pain, with or without associated leg pain, in the 3 months prior to the test day

-Other contraindications to exercise therapy like respiratory disease.

The subject's were screened with the help of Physical Activity Readiness Questionnaire,

(PAR-Q) (appendix B) which was completed on the day of the test. The exclusion criteria minimized any risk of adverse effects of testing in addition to soliciting subjects capable of performing the test.

### 6.3 Enrollment

The subjects were recruited from the University of Alberta, with the help of electronic mail and notices posted on student information boards and by classroom announcements. The posters contained the contact telephone number and e-mail of the investigator. Interested volunteers contacted the investigator via e-mail or telephone. Prospective subjects were given an information sheet (appendix C) regarding the study and testing. If they chose to participate, a time for them to visit the laboratory for testing was scheduled. If the subjects had any concerns about the study they were asked to contact the researcher at any time during the course of the study, and had the freedom to refuse participation without questions.

### 6.4 Data collection

#### 6.4.1 Examiner

A physiotherapist with sufficient knowledge of anatomy and physiology of the back

conducted the testing for all study subjects. The investigator was well versed with the Sorensen test and its performance, as well as the use of NIRS in measuring muscle deoxygenation and blood volume changes.

On the day of the test the subject was asked to complete data collection form (appendix D) and consent form (appendix E) along with the PAR-Q (appendix B). The PAR-Q screened potential subjects for cardiovascular and neurological risk factors and eliminated subjects where the inclusion criteria were not met. Testing was held in the Common Spinal Disorders Research Unit in the Department of Physical Therapy at the University of Alberta. Ethics approval was obtained prior to soliciting subjects and data collection. On the day of the test, the height (m), body mass (kg) and skin fold thickness (mm) was recorded for each subject. Skin fold thickness was measured using a pincer type caliper (Lange skinfold caliper, Cambridge Scientific Industries). The subject was asked to dress in shorts and remove his t-shirt. Using the anterior superior iliac spines as reference points the investigator traced posteriorly to the L4 vertebra. The subject was requested to bend over and the examiner traced one level up to the L3 vertebra. While the subject was lying prone the investigator lifted the fold of fat at the muscle belly of the right erector spinae near the L3 vertebra (approximately 3 cms from the midline of the spine) firmly with the thumb and the forefingers, pulling it away from the underlying

muscular tissue, following the natural contour of fat fold. The caliper was then placed and the thickness of the double layer of skin on the subcutaneous fat was directly read from the caliper dial in millimeters within two seconds of applying the jaws of the caliper (William et al., 1991). An average of three such readings was treated as the final value for each subject.

Next, the NIRS sensor, wrapped in celine wrap to prevent its contact with sweat, was attached on the right side of the erector spinae muscle belly at the L3 vertebra with the help of two elastic straps (approx 3cms away from mid line). The sensor was adjusted to have 4cms of penetration at 90mv of light intensity. The performance of the Sorenson test was explained to the subject with the help of a diagram. The subject lay prone on the plinth while the NIRS unit (Micro–Runman 96, NIT) was calibrated individually for every subject. After this, two minutes of baseline readings were taken. After two minutes, the subject moved his upper torso off the plinth to the level of the anterior superior iliac spine (ASIS) and rested his upper torso on a stool in preparation for the Sorenson test. The lower body was now stabilized with the help of two straps, one at the gluteal region and other at the ankle malleoli. A pillow was placed below the ankle and a towel placed at the hip and the ankle to avoid discomfort due to the straps. A sac suspended from the ceiling guided the horizontal trunk alignment at the interscapular region. At the prompt of

the investigator the subject extended his trunk, crossed his hands across the chest and maintained contact with the sac for as long as possible. The subject was occasionally encouraged with a prompt "you are doing fine, you are maintaining contact with the sac" until the test was terminated. There was no other communication once the test began until termination. This protocol has been proved to be reliable and valid in a variety of populations. Following test termination four minutes of recovery measurements were taken during which the subject was questioned regarding the reason for test termination.

**6.6 NIRS measurements**

NIRS demonstrates trends of muscle deoxygenation and blood volume changes. The instrument (MRM-96 with the NIRCOM software) is a non-invasive oxygen and blood volume trend monitor. It monitors the reflected light at 760 and 850 nm. At 760 nm deoxyhemoglobin and myoglobin absorb more light where as at 850 nm oxygenated hemoglobin and myoglobin absorb greater light. The difference between the lights reflected at these two wavelengths indicates a change in oxyhemoglobin (Bhambhani et al., 1998). NIRS measures the changes in tissue oxygenation of the small blood capillaries and venules.

The six independent variables, initial magnitude and rate of initial change of

deoxygenation from baseline, change in oxygenation and blood volume from baseline at test termination, magnitude of initial drop in blood volume and maximum increase in blood volume following the initial drop from baseline were plotted against absolute duration of holding time (sec). Baseline was defined as the average of the last 30 seconds just before the initiation of the Sorensen test (**A**, fig 1a). Absolute holding time (**H**, fig1a) was defined as the total length of time for which the Sorensen test was performed. Initial magnitude of deoxygenation was defined as the difference from baseline to the lowest point of the steep deoxygenation that occurred in the first few seconds of back extension (**B**, fig 1a). This point is further identified as the lowest point of the steep drop, terminating with any slight change in trend either in the direction of reoxygenation or leveling off. The rate of initial change in deoxygenation was the slope of a linear regression analysis of the initial magnitude of deoxygenation (**C**, fig 1a). Similarly, change in oxygenation and blood volume refered to the difference from baseline to the endpoint of contraction at test termination (**D** and **G**, fig 1a). Magnitude of initial drop in blood volume and maximum increase in blood volume following the initial drop was defined as the difference from baseline to the minimum and maximum value during test performance (**E** and **F**, fig 1a).

**7.0 Data analysis**

Descriptive statistics (means ± standard deviations) for the study group were computed for age (yrs), height (m), body mass (kg), and the skin fold thickness (mm) (table 1). Body mass index was calculated as weight/height$^2$ (kg/m$^2$). Pearson's product correlation coefficients (r) were used to estimate the degree of association between each of the following NIRS measures and absolute holding time (H) on the Sorensen test:

*Magnitude of initial deoxygenation from baseline (B)

*Rate of initial change of deoxygenation (slope of initial magnitude of deoxygenation) (C)

*Change in oxygenation at test termination from baseline (D)

*Magnitude of initial drop in blood volume from baseline (E)

*Maximum increase in blood volume following the initial drop from baseline (F)

* Change in blood volume from baseline at test termination (G)

(Refer to figure 1a)

Linear regression analysis was used to examine the relationship between the relative endurance time expressed as a percentage of SBME time and the delta values of oxygenation and blood volume (fig 3).

Linear regression was used to examine the relationship between skin fold thickness and absolute holding time, initial magnitude of deoxygenation and maximum increase in blood volume (fig 10-12).

# CHAPTER FIVE

## 8.0 Results

### Subject characteristics

Thirty-six healthy male subjects without a prior history of LBP participated in the current study. Their average age was 24 years (S.D±3.4), ranging from 19 to34 years. Most subjects had an active life style with 70% participating in vigorous exercise more than 30 minutes three times a week. Anthropometric characteristics of the subjects are provided in Table 1. Majority of subjects (70%) identified 'fatigue in the back' as a reason for test termination, while the rest reported 'pain in the thighs and calves' as criteria to end the test.

### Muscle oxygenation and blood volume trends

The analysis identified two distinct profiles for oxygenation and blood volume, with the majority of subjects (27) displaying a typical trend of deoxygenation and restriction of blood volume during the performance of the Sorensen test (Figure 1a). Conversely, a minority of subjects (9) demonstrated a steady rise in tissue oxygenation and blood volume during test performance (Figure 2a). Examples of the two distinct profiles are in figures 1 and 2, each being divided into three phases representing (a) baseline, (b) Sorensen test performance and (c) recovery. A typical pattern of initial sudden

deoxygenation and reduction of blood volume to the erector spinae muscles was seen in the first few seconds of static back extension (figure 1a). Following this there was a mild increase in blood volume and oxygen saturation within the muscle, leveling off in the latter part of contraction. During recovery (phase c) there was an immediate increase in blood volume and oxygen saturation that exceeded the resting baseline value during the first two minutes (hyperaemia) with a leveling off during the final 2 minutes. During contraction (fig 1a, phase b) signals from the 760 and 850 wavelengths of near infrared light on which the oxygenation and blood volume trends are based, show an upward deflection in phase (b), indicating greater reflection of light by oxyhemoglobin. As the amount of light reflected and the percentage saturation of oxyhemoglobin are inversely related, greater reflection determines decreased saturation of hemoglobin with oxygen (manual of NIRCOM software, 1997). The relative change in total blood volume is depicted as the sum signal of these two wavelengths (760+850 mv).

An example of the pattern of changes in oxygen saturation and blood volume observed in 9 subjects who formed an anomalous group can be found in figure 2b. In this group of subjects, during the performance of the Sorensen test (phase b) a steady rise in blood volume was accompanied by an increase in tissue oxygen saturation, followed by a leveling off. The absorbency at 760 and 850nm of infrared light showed a downward

deflection, demonstrating lesser reflection and higher levels of oxyhemoglobin during muscular contraction. Recovery indicated a sudden decrease in blood volume and oxygen saturation followed by a moderate rise in both (phase c).

Regression analysis indicated a linear relationship between the relative endurance time on the SBME (progressive tenth percentiles of subjects' maximum holding time) and changes in blood volume (r=0.7, fig 3). Similarly a linear relationship was observed for changes in oxygenation with increasing percentage of maximum contraction (r=0.7, fig 3).

**Relationship between SBME and muscle oxygenation/ blood volume**

Subjects (n=9) with an opposing anomalous trend in oxygenation and blood volume were excluded from further data analysis. For the remaining 27 subjects (table 1), scatter plots and pearson's correlation coefficients revealed insignificant correlations between duration of holding time and the six independent NIRS variables which were hypothesized as probable indicators of physiologic fatigue (r=0.005 to 0.09, Table 2, fig 4-9). Average values for the Sorensen test and the NIRS variables are presented in table 3. The average value for holding time is comparable to other studies on normal male subjects, which have ranged from 84 to 195 seconds (Gibbons et al., 1997, Latikka et al., 1995, Kankaanpaa et al., 1998, Jorgensen et al., 1987, Biering Sorensen., 1984).

**Relationship between skin fold thickness, NIRS measures and holding time**

Two of the six NIRS variables examined were found to be correlated with skin fold thickness. Initial magnitude of deoxygenation and maximum change in blood volume following the initial drop from baseline were positively correlated with skin fold thickness (r=0.5 and 0.2, respectively). Also, absolute holding time and skin fold thickness were found to be negatively correlated (r=0.2) (fig 10-12).

**Table 1**. General subject characteristics of all participants and those included in analysis

| | All participants (n=36) | | Subjects included in analysis (n=27) | |
|---|---|---|---|---|
| | **Range** | **Mean (S.D)** | **Range** | **Mean (S.D)** |
| **Age (yrs)** | 19-34 | 24 (3.3) | 19-34 | 24 (3.4) |
| **Height (m)** | 1.58-1.85 | 1.75 (0.06) | 1.58-1.85 | 1.75 (0.06) |
| **Bodymass (kg)** | 50-97.5 | 76.4 (9.69) | 50-96 | 75.6 (10.3) |
| **Bodymass index BMI ($kg/m^2$)** | 18-29.7 | 24.1 (4.7) | 18-29 | 23.9 (5.4) |
| **Skinfold thickness (mm)** | 7-21 | 13.4 (3.4) | 7-21 | 13.7 (3.6) |

**Table 2**: Pearson's correlation coefficients of NIRS measures and total duration of holding time (sec)

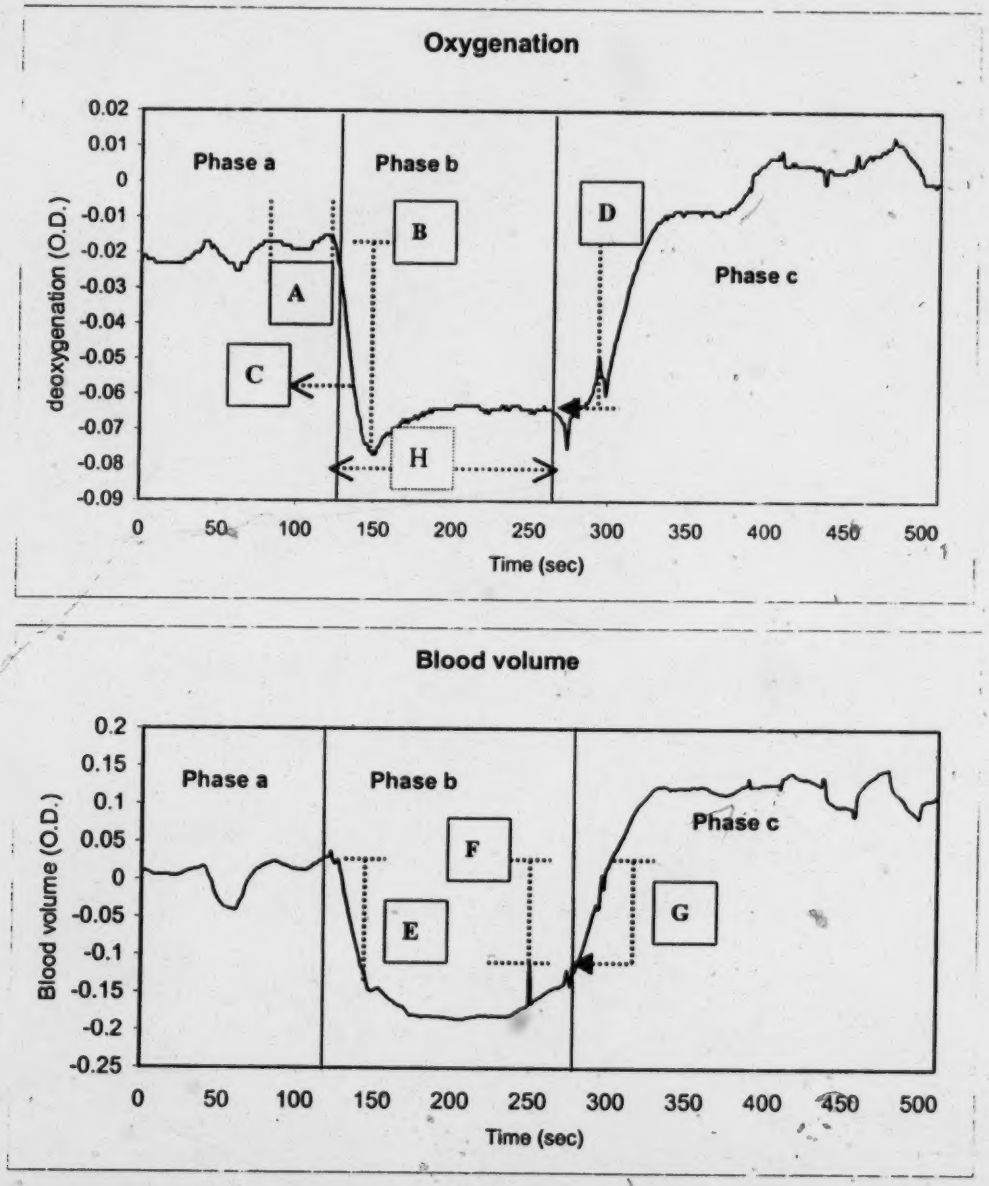
| NIRS measures | Pearson's correlation (r) |
|---|---|
| 1.Initial magnitude of deoxygenation from baseline | 0.05 |
| 2.Change in oxygenation from baseline at test termination | 0.01 |
| 3.Rate of initial change in deoxygenation from baseline | 0.05 |
| 4.Magnitude of initial drop in blood volume from baseline | 0.02 |
| 5.Maximum increase in blood volume following the initial drop from baseline | 0.09 |
| 6.Change in blood volume from baseline at test termination | 0.08 |

**Table 3**. Average values for Sorensen test and independent NIRS variables (n= 27)

| Sorensen test and NIRS measures | Mean (S.D.) |
|---|---|
| Absolute holding time (sec) | 126 (42) |
| Initial magnitude of deoxygenation from baseline (O.D) | 0.109 (0.2) |
| Change in oxygenation from baseline (O.D) | 0.102 (0.1) |
| Rate of initial change in deoxygenation from baseline (O.D) | -0.005 (0.01) |
| Magnitude of initial drop in blood volume from baseline (O.D) | 0.387 (0.7) |
| Maximum increase in blood volume following the initial drop from baseline (O.D) | 0.02 (0.6) |
| Change in blood volume from baseline at test termination (O.D) | 0.193 (0.7) |

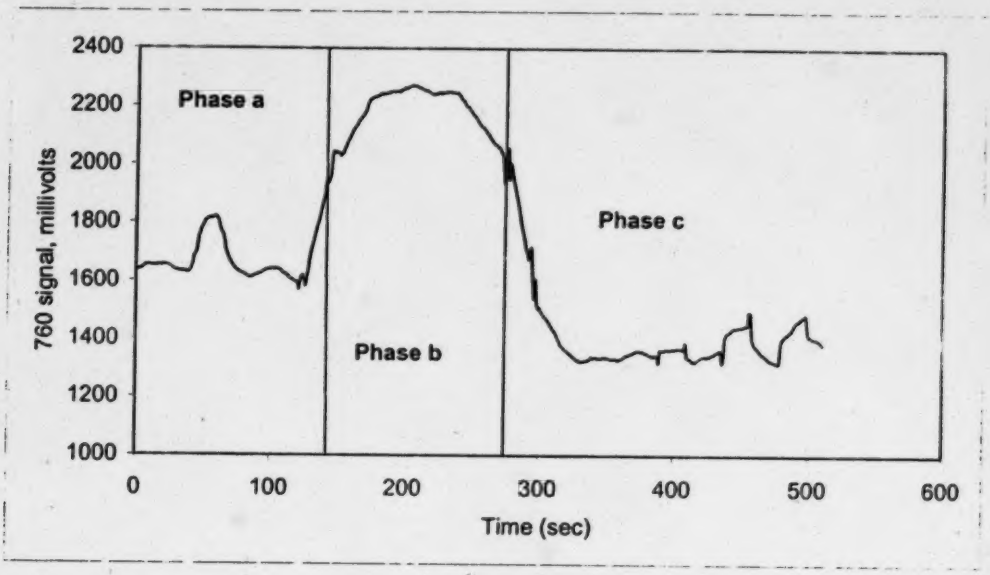
**(O.D) Optical Density**

**Figure 1a.** Oxygenation and blood volume trends during the Sorensen test in a typical subject (n=27)




**A=Baseline, B=Initial magnitude of deoxygenation, C=Rate of initial change in deoxygenation, D=Change in oxygenation from baseline, E=Magnitude of initial drop in blood volume, F=Maximum increase in blood volume following the initial drop from baseline, G=Change in blood volume at test termination, H=absolute holding time.**

**Figure 1b.** Absorbency at 760 and 850 nm during the Sorensen test.



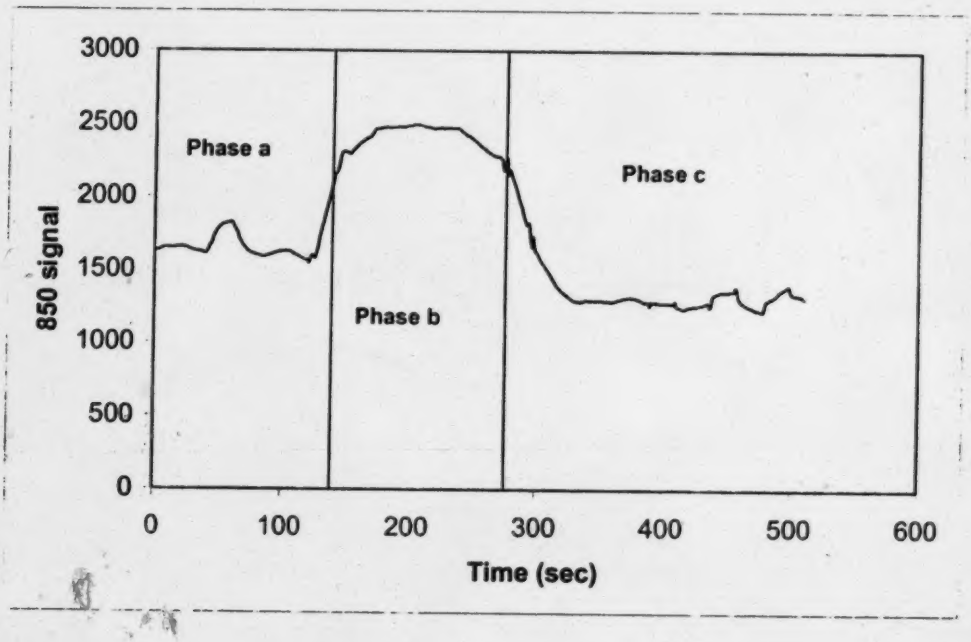
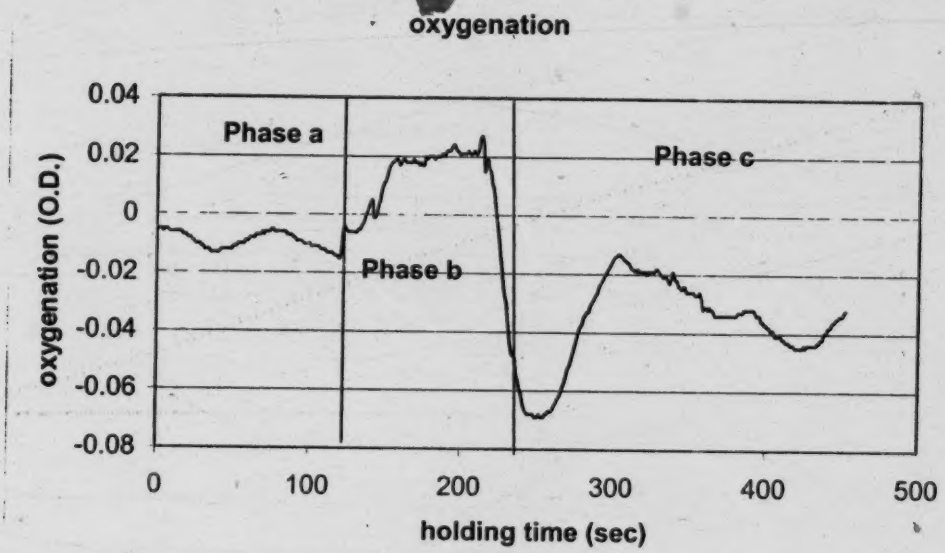



**Figure 2a.** A profile of oxygenation and blood volume during the Sorensen test in the anomalous group



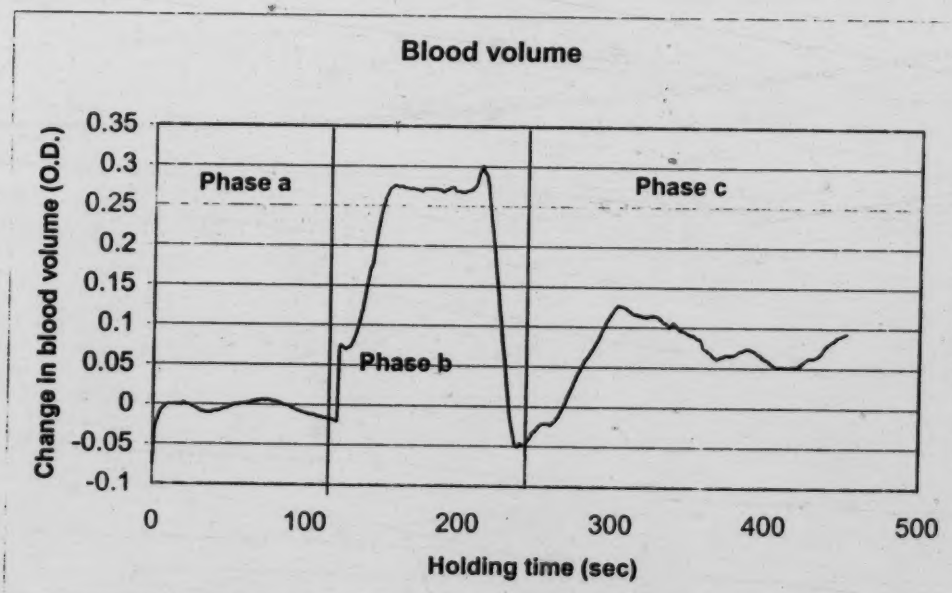
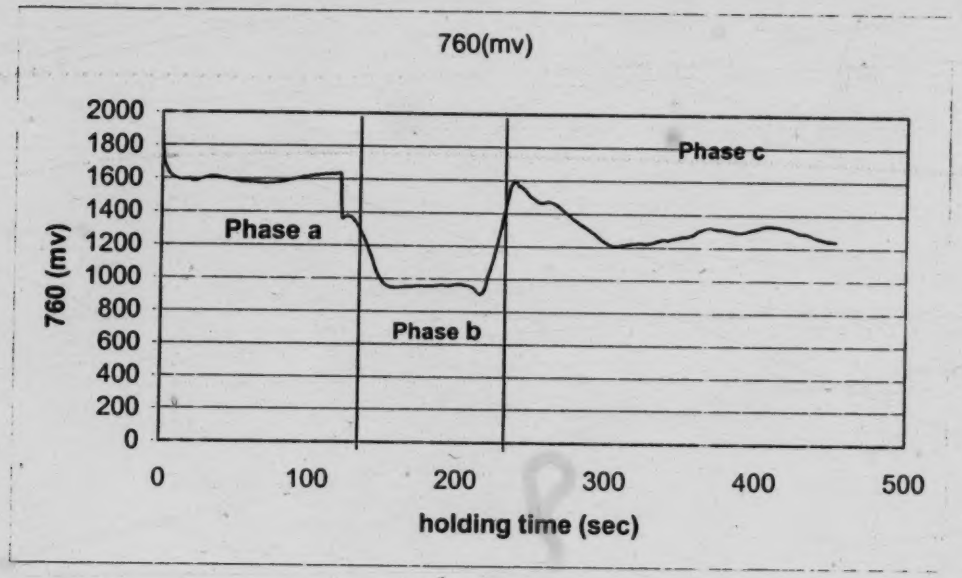



**Figure 2b. Absorbency at 760 and 850 nm during the Sorensen test.**



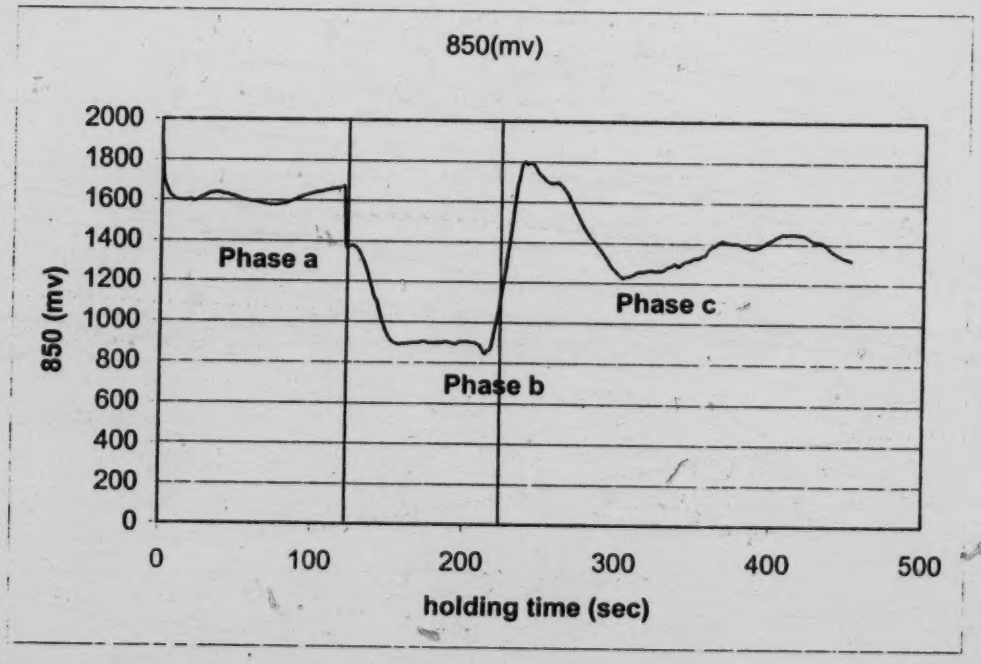
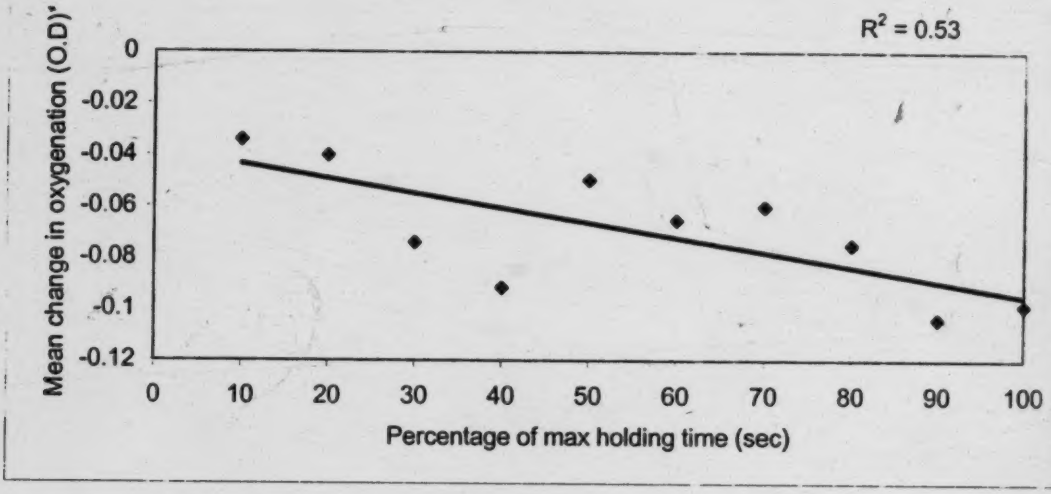
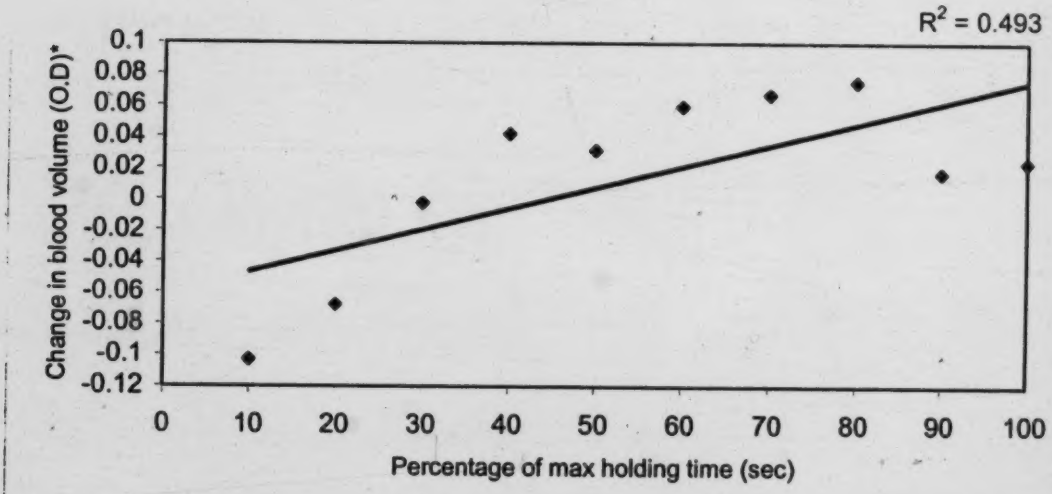



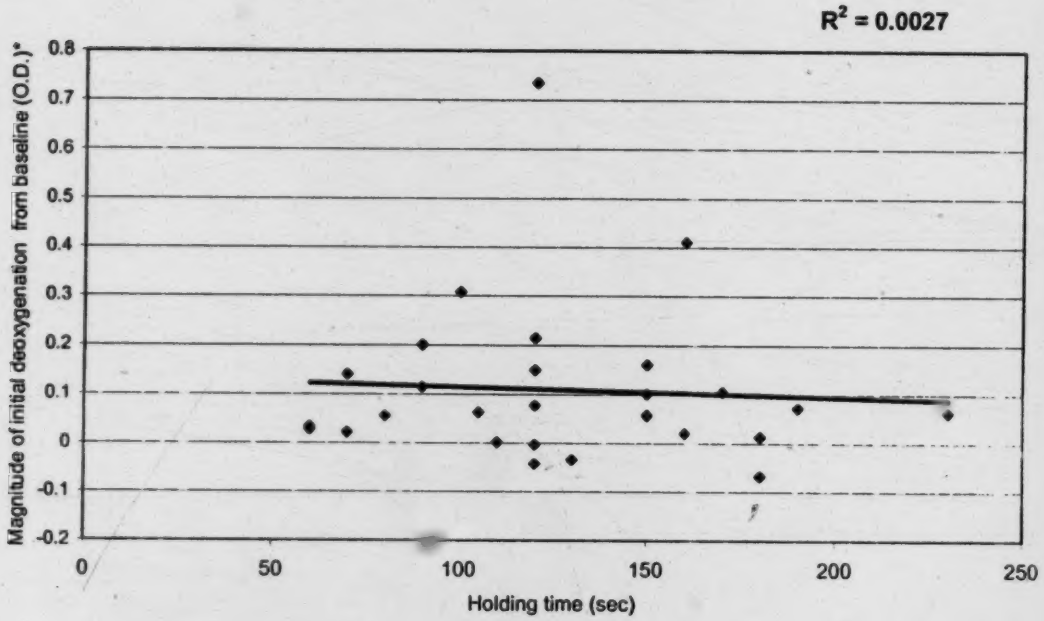
**Figure 3**. Mean change in tissue oxygenation and blood volume during performance of the Sorensen test (regardless of holding time)



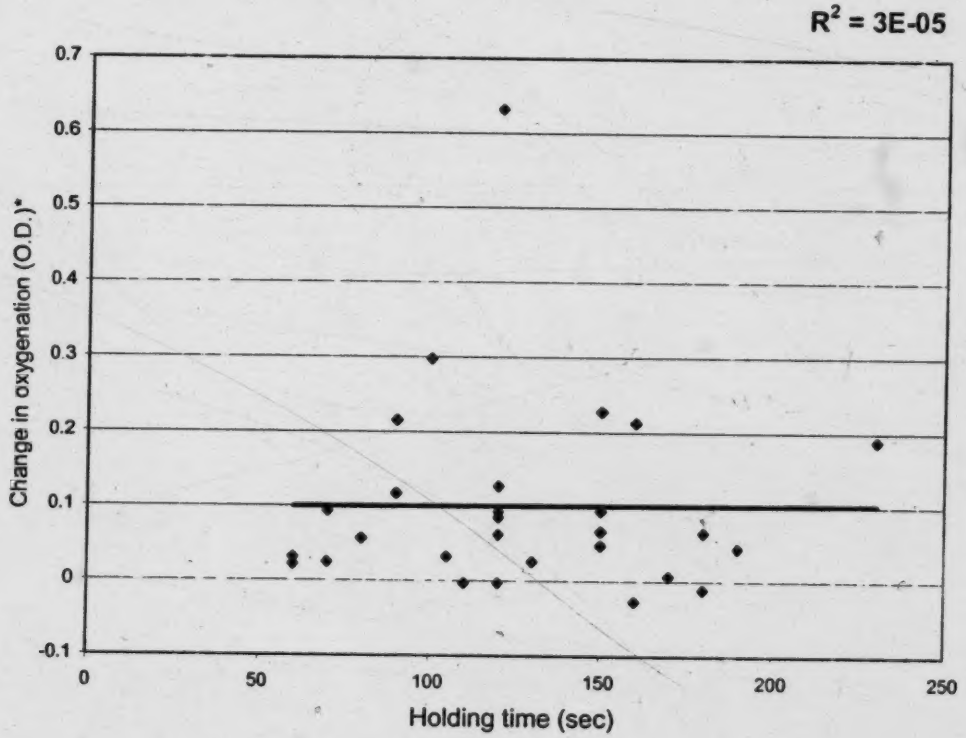

*** Optical density**

**Figure 4**: Relationship between magnitude of initial deoxygenation and absolute holding time (n=27)



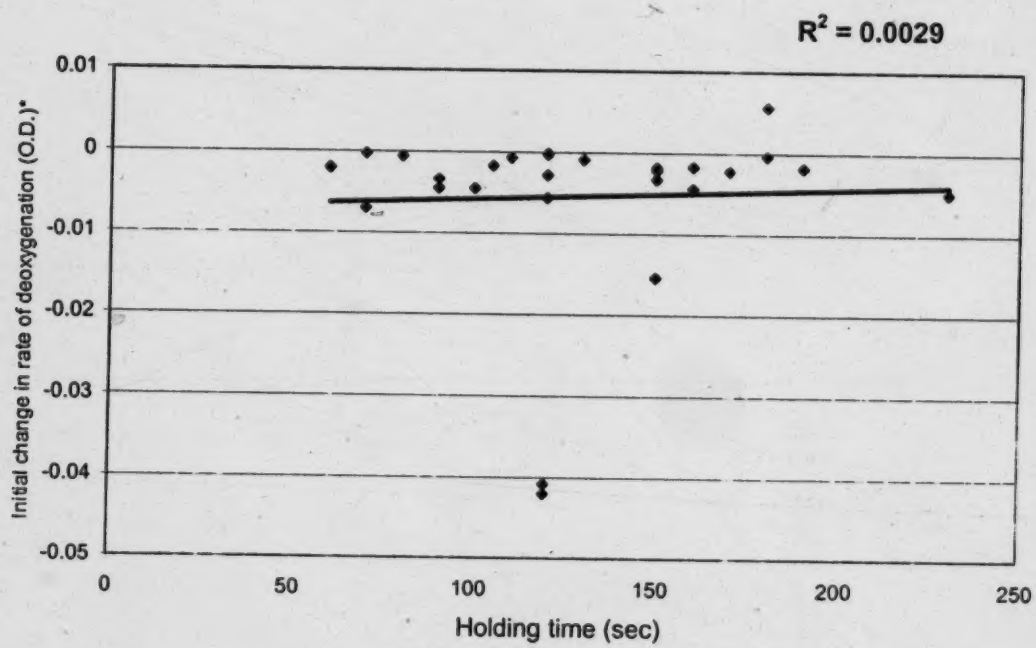

*** Optical Density (O.D.)**

**Figure 5**: Relationship between change in oxygenation from baseline to test termination and absolute holding time (n=27)



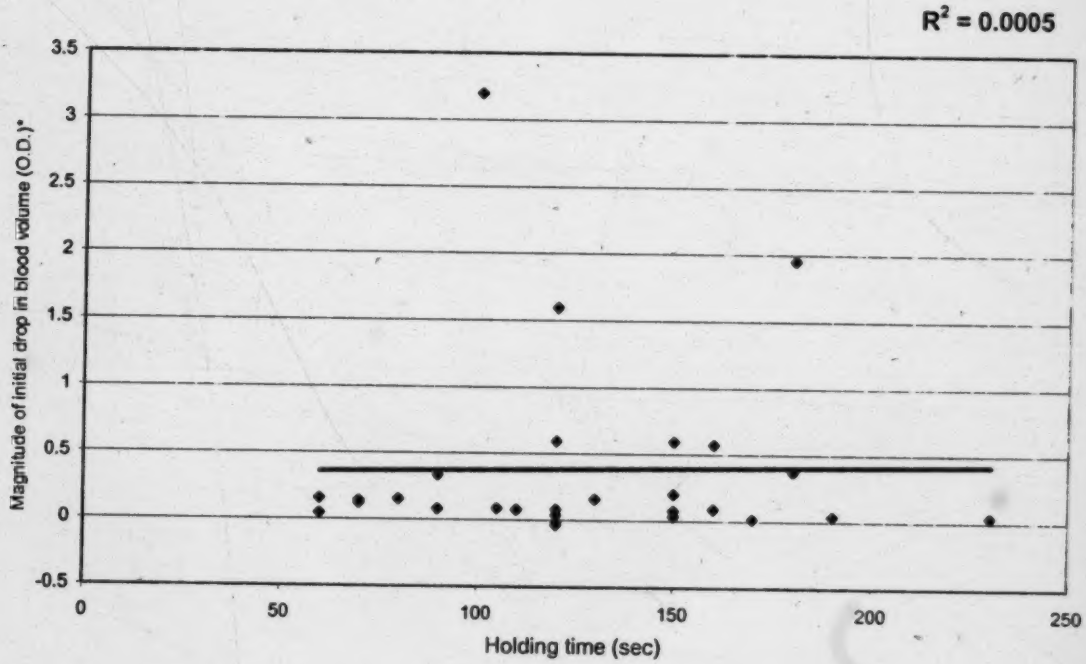

*** Optical density (O.D.)**

**Figure 6**: Relationship between rate of initial change in deoxygenation from baseline and absolute holding time (n=27)



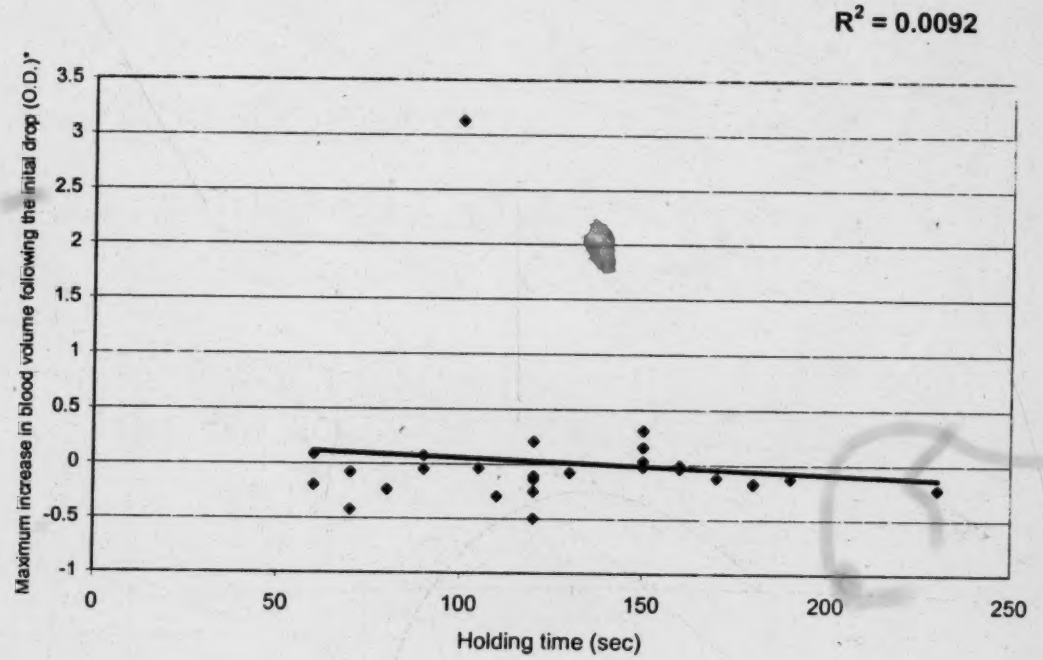

*** Optical density**

**Figure 7**: Relationship between magnitude of initial drop in blood volume from baseline and absolute holding time (n=27)



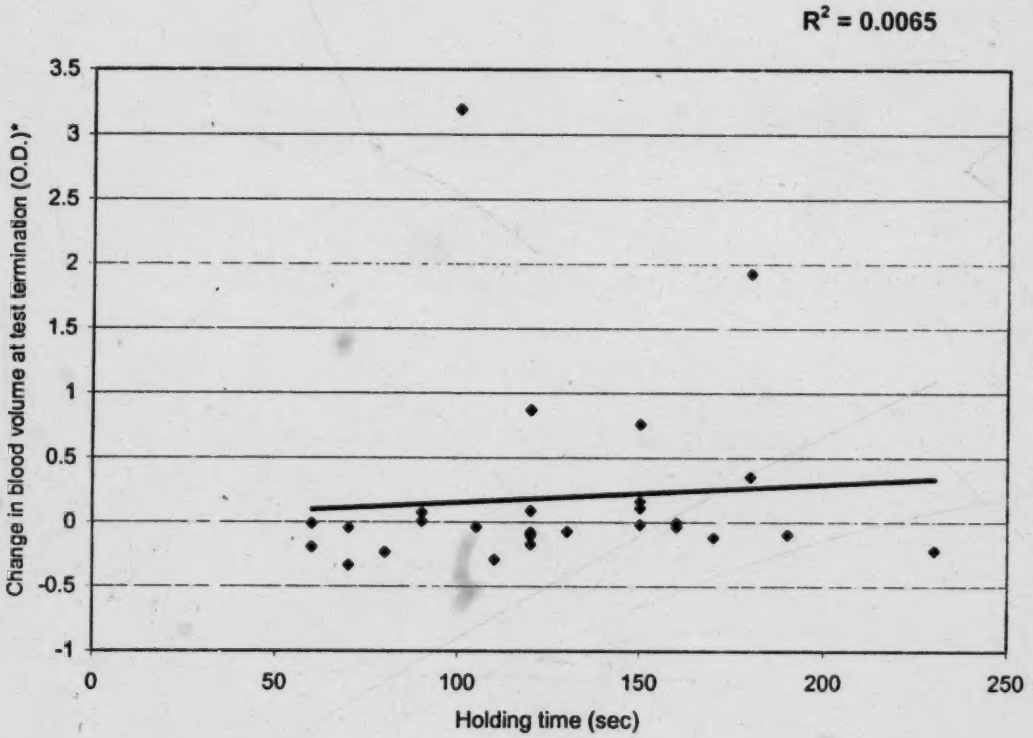

*** Optical density**

**Figure 8**: Relationship between maximum increase in blood volume following the initial drop from baseline and absolute holding time (n=27)




*** Optical density**

**Figure 9**: Relationship between change in blood volume at test termination from baseline and absolute holding time (n=27)




*** Optical density**

**Figure 10:** Relationship between skin fold thickness and absolute holding time (n=27)

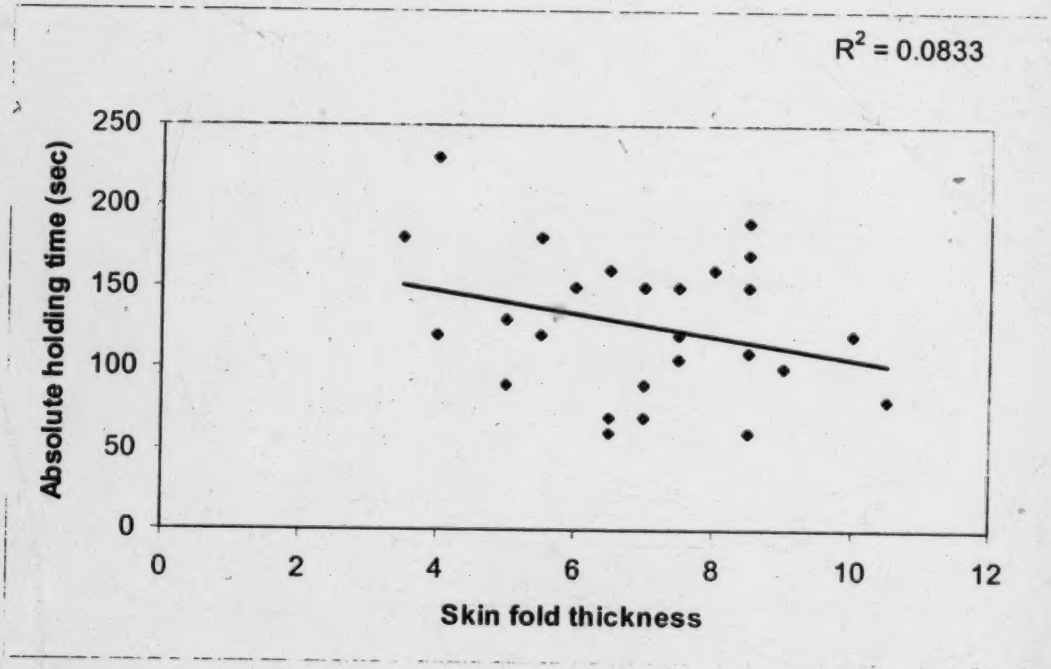


**Figure 11:** Relationship between skin fold thickness and initial magnitude of deoxygenation (n=27)

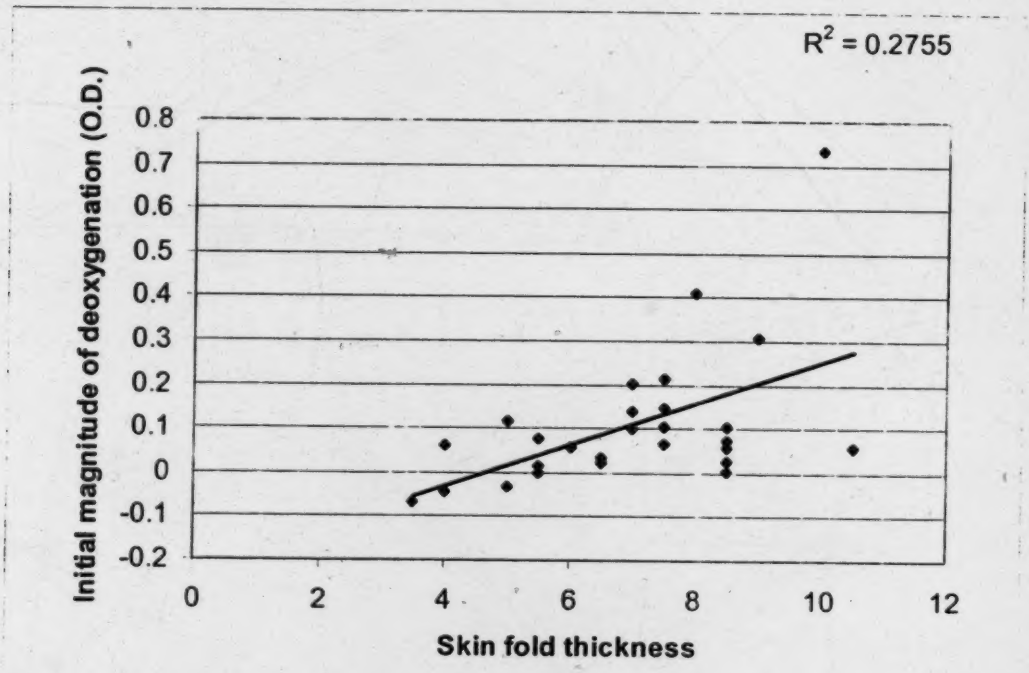
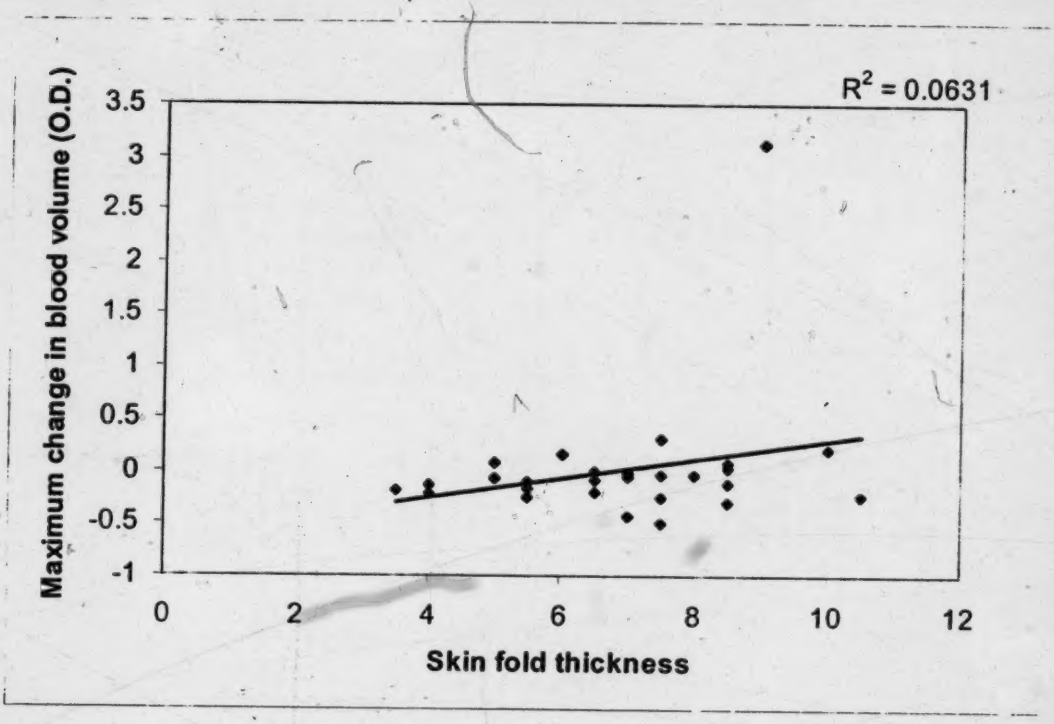


**Figure 12:** Relationship between skin fold thickness maximum change in blood volume following the initial drop from baseline (n=27)



# CHAPTER SIX

## 9.0 Discussion

### 1) Main result

The Sorensen test has commonly been used since 1984 as a measure of SBME, but its validity to explicitly measure static endurance of the back extensors has been questioned (Mofforoid et al., 1994, Kankaanpaa et al., 1998). The concept of 'physiologic fatigue' at the tissue level represents a complex phenomenon that has not been clearly understood (Alfonsi et al., 1999). Restriction of blood flow and tissue deoxygenation are reported as important factors in the development of muscular fatigue (Yoshitake et al., 2001 and Murthy et al., 1999). To provide greater insight into the role of physiologic fatigue with respect to test performance and thereby its effects on static endurance capacity of the back extensors, the current study investigated tissue deoxygenation and blood volume changes in relation to absolute holding time on the Sorensen test. Six NIRS measures (initial magnitude and rate of initial change in deoxygenation, change in oxygenation and blood volume from baseline at test termination, magnitude of initial drop in blood volume and maximum increase in blood volume following the initial drop from baseline) were investigated as possible determinants of maximum holding time on the Sorensen test (refer to pg 36). No association was found between any of these factors and Sorensen test performance (table 2, fig 4-9). This study is unique because it

examined changes in tissue oxygenation and blood volume during maximum voluntary contraction in Sorensen test performance.

An isometric contraction is dependent up on aerobic and anaerobic energy systems. Energy for short periods of high intensity isometric contractions is provided initially by aerobic metabolism followed by anaerobic metabolism. The aerobic component comprises of alactic aerobic (ATP-PC system) and a lactic anaerobic (breakdown of glycogen leads to production of lactic acid) systems. Intramuscular ATP and CP is the first energy storehouse tapped at the onset of contractile activity, but these energy stores deplete rapidly. As the isometric contraction proceeds, the blood vessels occlude due to an increase in intramuscular pressure, severely occluding the oxygen available to the muscle fibers. To keep pace with the increasing demand for oxygen, the fibers now depend on glycolysis for ATP production in the absence of energy. The end product of anaerobic glycolysis, pyruvic acid is converted to lactic acid. The essence of selecting the independent variables was to capture these distinct changes in energy production during static contraction of the back muscle (Sherwood, 1994).

**2) Muscle oxygenation and blood volume trends**

Two distinct trends for changes in oxygenation and blood volume were observed during test performance. The majority of subjects demonstrated a pattern of initial, sudden

deoxygenation followed by a more gradual decline or a leveling off in oxygen saturation. Simultaneously, there was a sudden decline in blood volume to the contracting muscle, followed by a leveling off or gradual increase in blood supply (Fig 1a). This finding is in agreement with other studies related to isometric contractions of the back or other muscles (Jensen et al., 1999, Yoshitake et al., 2001, Alfonsi et al., 1999, McGill et al., 2000, Homma et al., 1997, Murthy et al., 1997). Yoshitake (2001) suggested that the upper body works at 45% MVC during the performance of the Sorensen test. It has been found that muscle blood flow and hence the oxygen supply are restricted during static contractions of back extensors at 2-20% MVC creating an imbalance between oxygen supply and demand (Yoshitake et al., 2001, McGill et al., 2000, Jensen et al., 1999). This phenomenon is principally due to greater intramuscular pressure as compared to the intravascular pressure. The extraction of oxygen stores from oxy-hemoglobin and oxy-myoglobin continues, to try and meet the increasing physiological demands of energy, which explains the sudden drop in the level of oxygen and blood supply in the first 30 seconds of contraction. Once the muscle is depleted of its oxygen stores, the body makes homeostatic adjustments causing an increase in heart rate, blood pressure and decreased vascular resistance. Thereby, a greater volume of blood is being pumped with each systole and is directed to the region of highest physiologic demand. To enhance this effect there is redistribution of blood from the splanchnic circulation. These

mechanisms help compensate for the oxygen debt and explain the phenomenon of increased blood volume in the latter part of contraction (Jensen et al., 1999).

In the present study a few subjects displayed an opposite trend with a steady rise in the level of oxygen and blood volume during the Sorensen test (fig 2a). Three of nine subjects demonstrated slight deoxygenation followed by a steady rise, with six subjects representing a gradual increase in oxygen saturation and blood volume. Most subjects were right hand dominant and in such cases the left side of the back muscles has been suggested to be more active with adaptational changes of a greater proportion of type I fibers on the left side as compared to the right (Merletti, 1994). Thus, measures on the right side only may not have been adequate to capture more critical changes that may have been occurring on the left side of the back during test performance. The anomalous pattern could suggest an early recovery on the right side as compared to the dominantly active left side in this subgroup of subjects.

The average trends for changes in blood volume indicated moderately high positive correlations with every tenth percentile of maximum holding time, regardless of the length of holding time, and high inverse correlations with trends of changes in oxygenation (Fig 3). During static exercise changes take place in the pulmonary ventilation, external respiration and internal respiration. There is an increase in minute ventilation, tidal volume and frequency of respiration. There is also an increase in alveolar ventilation but no change in partial pressure of

oxygen in the alveolus and the arterial blood. To enhance this effect the difference between the partial pressure of oxygen in the alveoli and the arteries increases and the percent saturation of oxygen in the arteries drops. At the tissue level, the partial pressure of oxygen in the venous blood decreases and the level of carbon dioxide increases. There is a decrease in the aterio-venous oxygen saturation. All of the above suggests an increased utilization of oxygen with increasing demand for energy. Secondly, there is a reduction in blood flow due to decreased preload (increased intrathoracic pressure→decreased venous return to the heart) and increased after load (increase in mean arterial pressure). To compensate for the increased energy expenditure, heart rate increases and this encourages a stimulus for greater blood flow. This possibly explains the positive trend of average increase in blood volume with increasing percentile of maximum holding time. At this time the oxygen dissociation curve shifts to the right due to decreased pH, high temperature and excessive carbon dioxide. In addition a chemical 2,3 diphosphoglycerate increases in the RBC during intense exercise enhancing the curve to the right. All these circumstances cause easy dissociation of oxygen but retard its uptake at the lung reducing the partial pressure of oxygen in the arteries. This creates further imbalance between oxygen supply and demand (Chaudhuri, 1991, Plowman and Smith, 1996) and helps explain the negative trend between oxygen saturation and increasing percentage of maximum holding time.

**3) Relationship between endurance time and changes in muscle oxygenation and blood volume**

All of the independent NIRS variables of changes in oxygenation and blood volume had little or no correlation with holding time on the Sorensen test, thus failing to explain static endurance capacity of the back extensors as indicated through Sorensen test performance (table 2, fig 4-9). Our negative findings could be explained by greater muscle activation at a site other than the right lumbar region limiting test performance or a failure of the specific NIRS measures selected to adequately reflect muscle fatigue.

i) Due to evidence suggesting greater left side muscle activity in a right hand dominant individual (Merletti et al. 1994), a greater contribution from the left side of the back muscles may have been present in this particular group of subjects. The trunk extensors have a large relative cross-sectional area of slow twitch fibers, and these fibers are comparatively larger than fast twitch fibers. For example, the longissimus dorsi muscle has been shown to have 71% slow twitch as compared to 54-55% in the multifidus and iliocostalis. The slow twitch fibers have a low ATP turnover as compared to fast twitch, and a low cost for cross bridge cycling and therefore have a high net efficiency. The blood irrigation is not compromised due to the exposure to a large capillary bed. These fibers are slow in their rate of substrate utilization, and have a large myoglobin and mitochondrial content. When the paraspinals are stimulated there

is a redistribution of force components to other parts of the musculature (Jorgensen, 1995). When the longissimus dorsi was stimulated by myoelectric signals, Merletti (1994) reported greater use of muscle groups on the non-dominant side to compensate for moments applied to the dominant side. Also, Bagnall et al (1994) observed greater percentage of type I fibers of the dorsal column (multifidus and sacrospinalis) on the left as compared to the right side. Most of the subjects in this study were right handed suggesting that these subjects used the left side of their body to a greater extent than the right with their left side having a greater percentage of type I fibers. Jensen (1999) examined greater intramuscular pressure on the left as compared to the right during static extensions of the erector spinae in standing position with a dynamometer. Thus, the readings from right side of the erector spinae, may not represent the muscle mass most active in determining endurance capacity of an individual. However, Mannion (1997) reported no significant differences between the right and left sides of the erector spinae during the performance of the Sorensen test in pre-dominantly right-handed group of subjects.

ii) An EMG study by Jensen (1999) measured greater force development in the thoracic region (T12) as compared to the lumbar region (left L4) during static contractions of the back. Also, the erector spinae group of muscles in the thoracic region has been reported to have a higher percentage of type I fibers as compared to the lumbar region (Mannion et al., 1994). With greater force development in the thoracic region during static contractions of the back, there

would be a higher intramuscular pressure in comparison to arterial pressure resulting in greater restriction of blood flow to this region as compared to the lumbar area. This creates an imbalance between oxygen supply and demand that would be more enhanced in the thoracic region (Jorgensen, 1997). Hence, during the performance of the Sorensen test the thoracic region may be exerted to a greater extent than the lumbar. Therefore, the lumbar region may not be the one that limits the maximum holding time during the Sorensen test.

iii) Activity of hip extensors along with back extensor muscles has been found with EMG during the performance of the Sorensen test (Mofforoid et al., 1994 and Kankaanpaa et al., 1998).

iv) Other factors such as motivation have been reported to play a role in Sorensen test performance (Sorensen 1984, Mofforoid et al., 1994 and Kankaanpaa et al., 1998). In the current study 70% of the young healthy men involved in vigorous exercise for greater than 30 minutes three times a week. These subjects would be expected to be highly motivated in their test performance. However, motivation was not measured in this study.

**4) Relationship between skin fold thickness and NIRS measures**

Increasing skin fold thickness was associated with a decrease in absolute holding time, greater initial magnitude of deoxygenation and maximum increase in blood volume. These results are

supported by similar finding in other studies (Yamamoto et al., 1998 and Beekvelt et al., 2001). A two-fold increase in fat layer results in a decrease in sensitivity of measurement due to diminished intensity of detected light (Yamamoto et al., 1998). This suggests that the muscle oxygen consumption would be underestimated as fat layer increases, due to a mixture of signal originating from the adipose tissue and the muscle with greater contribution from the adipose tissue (Beekvelt et al, 2001). The greater decline in deoxygenation could merely be a result of lesser intensity of light reaching the target tissues and hence not representative of the changes within the muscle tissue.

Study limitations :

This study has several limitations that may have affected the results.

1) Possible effects of variations in the subject upper body mass (mass of the trunk, arms and head) were not controlled. Jorgensen (1986) reported shorter endurance capacity among subjects with higher upper body weight. There was great variation in body mass among the subjects (50 to 96 kgs), which may affect upper body weight and hence endurance capacity.

2) Motivation has been suggested to affect test performance but this factor was not accounted for in this study (Sorensen 1984, Mofforoid, 1994 and Kankaanpaa 1998).

3) Since the thoracic region may experience greater stress than the lumbar region and the left and right sides may participate to different extents in the performance of the Sorensen test, placement of more than one probe would help identify the physiological responses at both sites which may be important in determining endurance capacity.

4) Skin fold thickness has been demonstrated to affect path length of the signal. This study included subjects with a wide variation in their skin fold thickness (7-21mm), which could have influenced our findings.

Future researchers should consider the use of three probes (T12, left L4, right L4) to help understand physiological responses at these recording sites. The use of EMG and NIRS simultaneously would help in understanding the electrophysiological and blood volume changes during static contractions of the back extensors. EMG helps define local fatigue in isometric contractions (Yoshitake, 2001). A compression of the power spectrum to lower frequencies is observed at the time of fatigue (Mannion et al., 1994). There is also a decline in median density frequency of the power spectrum, and decrease in the mean fiber conduction velocity (Alfonsi et al., 1999, Mannion et al., 1994).

From the results it can be concluded that either the NIRS measures used are not detecting the critical changes in oxygenation and blood volume in the back muscles indicative of fatigue

or that the Sorensen test is not a representative measure of static endurance capacity of the lumbar extensor muscles. It has been widely used because of its ease but it has several drawbacks. The weight of the trunk, arms and head and the position of the center of gravity determine the load. Weak relations between subjects with a smaller load to trunk extensor MVC, demonstrate poorer endurance than subjects with a larger load (Jorgensen, 1997). NIRS has proved to be a sensitive technique to detect differences in muscle deoxygenation at low-level static contractions (Murthy et al., 1997), and it has been used to evaluate ·· siological changes in the back extensors (Jensen et al., 1999, McGill et al., 2000). However, may be possible that the measures we have used to define physiologic fatigue may be inappropriate or inadequate.

# CHAPTER SEVEN

## 10.0 Conclusions

This study is the first to examine changes in tissue oxygenation and blood volume in the erector spinae during maximum voluntary isometric contraction in Sorensen test performance. The majority of the subjects displayed a typical trend of deoxygenation and restriction of blood supply, followed by hyperemia and increased oxygen saturation during recovery. In conclusion, no correlation was found between six NIRS measures of physiologic fatigue (initial magnitude of deoxygenation, rate of initial change in oxygenation from baseline, change in oxygenation and blood volume from baseline at test termination, minimum and maximum value in blood volume from baseline) and absolute holding time on the Sorensen test. These findings suggest that the specific NIRS measures used were not appropriate for determining physiologic changes of muscle fatigue or that the Sorensen test is not a representative measure of static endurance capacity of the lumbar extensors. Instead, the test could largely be determined by other factors, such as fatigue of the hip extensors or back extensors in the thoracic region, motivation or pain tolerance.

# REFERENCES

Alfonsi, E., Pavesi, R., Merlo, M., Gelmetti, A., Zambarbieri, D., Lago, P., Arrigo, P., Reggiani, C and Moglia A. Hemoglobin near-infrared spectroscopy and surface EMG study in muscle ischaemia and fatiguing isometric contraction. *Journal of Sports Medicine Physical Fitness,* 1999;39: 83-92.

Alaranta, H., Hurri, H., Heliovaara, M., Soukka, A and Harju R. Non-dynamometric trunk performance tests: reliability and normative data. *Scandinavian Journal of Rehabilitation Medicine*, 1994;26: 211-215.

Bagnall, K., Ford D., McFadden K., Green hill B and Raso P. The histochemical composition of human vertebral muscle. *Spine,* 1984;9: 470-473.

Beekvelt, V., Borghuis, M., Engelen V., Wevers R. and Colire W. Adipose tissue thickness in vivo quamtitative near-IR spectroscopy in human skeletal muscles. *Clinical Sciences*, 2001;101: 21-28.

Belardinelli, R., Barstow, T., Porszasz, J and Wasserman K. Skeletal muscle oxygenation during constant work rate exercise. *Medical Sciences Sports Exercise*, 1995;27(4): 512-519.

Belardinelli, R., Barstow, T., Porszasz, J and Wassernam K. Changes in skeletal muscle oxygenation during incremental exercise measured with near infrared spectroscopy.

*European Journal of Physiology*, 1995;70: 487-492.

Bhambhani, Y., Maikala, R., Jeon, J and Bell G. Reliability of tissue deoxygenation during cuff ischemia in healthy male. *Annual Scientific Conference- Canadian Society for Exercise Physiology,* Abstract, pp.3.

Bhambhani, Y., Maikala, R and Buckley S. Muscle oxygenation during incremental arm and leg exercise in men and women. *European Journal of Applied Physiology,* 1998;78: 422-431.

Blasi, R., Sfareni, R., Piettranico, B., Mega, A and Ferrari M. Non-invasive measurement of brachioradialis muscle VO2-blood flow relation during graded isometric exercise. *Advances in Experimental Medicine and Biology*, 1996;388: 293-298.

Chok, B., Lee, R., Latimer, J and Tan, B. Endurance training of the trunk extensor muscles in people with sub acute low back pain. *Physical Therapy,* 1999;79(11): 1032-1042.

Chok B. A comparison of the Sorensen test between subjects with and without subacute low back pain. *Physiotherapy Singapore*, 1999;2(2): 88-91.

Chaudhuri S. Concise Medical Physiology. Published by- Dr. Mita Sen, 1989: pp 86-503.

Costes, F., Barthelemy, J., Feasson, L., Busso, T., Geyssant, A and Denis C. Comparison

of muscle near Infrared spectroscopy and femoral blood gases during steady state exercise in humans. *Journal of Applied Physiology*, 1996;80(4): 1345-1350.

Deyo, R. Low Back Pain. *Scientific American Journal*, 1998; 49-53.

Dedering, A., Mikaela Roos af Hjelmaster., Elfving, B., HarmsRingdahl, Karin and Nemeth G. Between-days reliability of subjective and objective assessments of back extensor fatigue without lower-back pain. *Journal of Electromyography and Kinesiology, 2000*; 10: 51-158.

Feldman, D., Rossignol, M., Shrier, I. and Abenhaim, L. Smoking- A risk factor in the development of low back pain in adolescents. *Spine*, 1999;24(23): 2492-2496.

Gibbons, L., Videman, T and Battie M. Determinants of isokinetic and psychophysical lifting strength and static back muscle endurance. *Spine*, 1997;22 : 2983-90.

Gibbons, L., Latikka, P., Battie, M., Videman, T and Mannionen H. The association of trunk muscle cross sectional area and magnetic resonance image parameters with isokinetic, psychophysical lifting strength and static back muscle endurance in men. *Journal of Spinal Disorders*, 1997;10(5): 398-403.

Gibbons, L., Videman, T and Battie, M. Isokinetic and psychophysical lifting strength, static back muscle endurance, and magnetic resonance imaging of the para spinal muscles as predictors of low back pain in men. *Scandinavian Journal of Rehabilitation Medicine,*

1997;29: 187-191.

Gunner, B. Build up of fatigue in static work: role of blood flow In *Physical work and Effort*, 1997; volume 28: pp 145-157.

Gundewall, B., Liljeqvist, M and Hansson T. Primary Prevention of back symptoms and absence from work- A prospective randomized study among hospital employees. *Spine*, 1993;18(5): 587-594.

Hicks, A., McGill, S and Hughson R. Tissue oxygenation by near infrared spectroscopy and muscle blood flow during isometric contractions of the forearm. *Canadian Journal of Applied Physiology*, 1999; 24(3): 216-230.

Holmstrom, E.. Moritz, U and Anderson, M. Trunk muscle strength and back muscle endurance in construction workers with and without low back disorders. *Scandinavian Journal of Rehabilitation Medicine* 1992;24: 3-10.

Homma, S., Eda, H., Ogasawara, S and Kagaya A. Near Infrared estimation of oxygen supply and consumption in forearm muscles working at varying intensity. *Journal of Applied Physiology*, 1996, 1279-1284.

Holloszy, J and Coyle E. Adaptations of skeletal muscle to endurance exercise and their metabolic consequences. *Journal of Applied Physiology*, 1984, 56; 831-838.

Hultman, G., Nordin, M., Saraste, H and Ohlsen H. Body composition, endurance, strength, cross sectional area, and density of the MM erector spinae in men with and without low back pain. *Journal of Spinal Disorders*, 1993;6(2): 114-123.

Ito, T., Shirado, O., Suzuki, H., Takahashi, M., Kaneda, K and Strax T. Lumbar trunk muscle endurance training: An inexpensive alternative to a machine for evaluation. *Archives Physical Medicine Rehabilitation Journal*, 1996;77: 75-79.

Jensen, R., Jorgensen, K., Hargens, A., Pernille, K and Nicolaisen T. Physiological response to submaximal isometric contractions of the paravertebral muscles. *Spine*, 1999;24(22): 2332-2338.

Jorgensen, K and Tom, N. Two methods for determining trunk extensor endurance. A comparative study. *European Journal of Applied Physiology*, 1986;55: 639-644.

Jorgensen, K., Tom, N and Kato M. Muscle fiber distribution, capillary density, and enzymatic activities in the lumbar paravertebral muscles of young men. *Spine*, 1993;18(11): 1439-1450.

Jorgensen, K and Nicolaisen T. Trunk extensor endurance- determination and relation to low back trouble. *Ergonomics*, 1987;30(2): 259-267.

Jorgensen K. Human trunk extensor muscles-Physiology and ergonomics. *Acta Physiologica Scandinavia* 1997;160 (Supplement 637)

Kahanovitz, N., Nordin, M., Verderame, R., Yabut, S., Parnianpour, M., Voila, K and Mulvihill, M. Normal Trunk Muscle Strength and Endurance in Women and the effect of exercises and Electrical Stimulation. *Spine*, 1987;12(2): 112-118.

Kankaanpaa, M., Laaksonen, D., Taimela, S., Kokko, S., Airaksinen, O and Hannien, O. Age, sex and body mass index as determinants of back and hip extensor fatigue in the isometric Sorensen back endurance test. *Archives Physical Medicine Rehabilitation,* 1998;79: 1069-1075.

Keller, A., Hellesnes, J and Brox J. Reliability of the isokinetic trunk extensor test, Biering-Sorensen and Astrand Bicycle test. Assessment of Intraclass Coefficient and Critical difference in patients with chronic low back pain and healthy individuals. *Spine,* 2001;26(7): 771-777.

Kraemer, H and Theimann S. How many subjects? SAGE publications, 1987: pp-53-59.

Latza, U., Kohlmann, T., Deck, R and Raspe, H. Influence of occupational factors on the relation between socioeconomic status and self reported back pain in a population-based sample of German adults with back pain. *Spine*, 2000;25(11): 1390-1397.

Latimer, J., Maher, C., Refshauge, K and Colaco I. The reliability and validity of the biering Sorensen test in symptomatic subjects and subjects reporting current or previous nonspecific low back pain. *Spine*, 1999;24(20): 2085-2090.

Latikka, P., Battie, M., Videman, T and Gibbons, L. Correlations of isokinetic and psychophysical and static back extensor endurance tests in men. *Clinical Biomechanics,* 1995;10(6): 325-330.

Luoto, S., Heliovaara, M., Hurri, H and Alaranta H. Static back endurance and the risk of low back pain. *Clinical Biomechanics,* 1995;10(6): 323-324.

Mayer, T., Gatchel, R., Betancur, J and Bovasso, E. Trunk muscle endurance measurement. *Spine,* 1995;20(8): 920-927.

Mannion, A., Dumas, G., Stevenson, J and Cooper R. The influence of muscle fiber size and type distribution on electromyographic measures of back muscle fatigability. *Spine,* 1998;23(5): 576-584.

Maikala, R and Bhambhani Y. Muscle oxygenation trends using near-infrared spectroscopy (NIRS). *The second International Cyberspace Conference on Ergonomics,* 1999; 542-557.

Maikala, R., Farag, M and Bhambhani, Y. Low back muscle oxygenation trends during simple postural variations-*Intersession reliability using Infrared spectroscopy*: pp.1-4

Mancini, D., Bolinger, L., Li, H., Kendrick, K., Chance, B and Wilson J. Validation of near-infrared spectroscopy in humans. *Journal of Applied Physiology,* 1994;77(6):

2740-2747.

MacDonald, M., Tarnopolsky, M., Green, H and Hughson R. Comparison of femoral blood gases and muscle near-infra red spectroscopy at exercise onset in humans. *Journal of Applied Physiology*, 1999;86(2): 687-693.

McCully, K and Hamaoka T. Near Infrared Spectroscopy: What can it tell us about oxygen saturation in skeletal muscle? *Exercise and Sports Sciences Review*, 2000; 28(3): 123-127.

McGill, S., Richard, H and Kellie, P. Lumbar erector spinae oxygenation during prolonged contraction. *Ergonomics*, 2000;43(4): 486-493.

Merletti, R., Carlo, J., Luca, De and Sathyan, D. Electrically evoked myoelectric signals in back muscles: effect of side dominance. *Journal of Applied Physiology*, 1994;77 (5): 2104-2114.

Moffroid, M., Reid, S., Henry, S., Haugh, L and Ricamato, A. Some endurance measures in persons with chronic low back pain. *Journal of Sports Physical Therapy*, 1994;20(2): 81-87.

Moreland, J., Finch, E., Stratford, P., Balsor, B and Gill, C. Inter-rater reliability of six tests of trunk muscle function and endurance. *Journal of Sports Physical Therapy*, 1997;26(4): 201-208.

Murthy, G., Kahan, N., Hargens,A and Rempel, D. Forearm muscle oxygenation decreases with low levels of voluntary contraction. *Journal of Orthopedic Research*, 1997;15: 507-513.

Nicolaisen, T and Kurt, J. Trunk strength, back muscle endurance, and low back trouble. *Scandinavian Journal of Rehabilitation Medicine*, 1985;12: 121-127.

Novy, D., Simmonds, M., Olson, S., Lee, E and Jones, S. Physical Performance: Differences in men and women with and without low back pain. *Archives Physical therapy Medicine Rehabilitation*, 1998;80: 195-198.

Peterson, C., Jennifer, E and Angela, R. A cross sectional study correlating lumbar spine degeneration with disability and pain. *Spine*. 2000;25(2): 218-223

Plowman, S and Smith, D. Exercise physiology for health fitness and performance. Published by: Plowman, Sharron A 1997.

Simmonds, M., Olson, S., Jones, S., Hussein, T., Lee, E., Novy, D and Radwan, H Psychometric characteristics and clinical usefulness of physical performance tests in patients with low back pain. *Spine*, 1998;23(22): 2412-2421.

Sorensen-Biering F. Physical measurements as risk indicators for low back pain over a one-year follow up. *Spine*, 1984;9(2): 106-119.

Takala, E and Juntura, E. Do functional tests predict low back pain? *Spine*, 2000;25 (6): 2126-2132.

Thorbjornsson, C., Alfredsson, L., Fredriksson, K., Michelesen, H., Punnett, L., Vingard, E., Torgen, M and Kilbom, A. Physical and psychological factors related to low back pain during a 24-year period. *Spine*, 2000;25(3): 369-375.

William, D., Frank, K and Victor K. Exercise physiology: Energy, nutrition and human performance. Smith J.M, *Exercise Physiology*, 1991, third edition.

Yamamoto, K., Niwayama, M., Lin, L., Shiga, T., Kudo, N and Takahashi, M. Accurate NIRS measurement of muscle oxygenation by correcting the influence of subcutaneous fat layer. *Spine*, 1998; 3194: 166-173.

Yoshitake, Y., Ue, H., Miyazaki, M and Moritani. T. Assessment of lower-back muscle fatigue using electromyography, mechanomyography, and near-infrared spectroscopy. *European Journal Applied Physiology*, 2001; 84: 174-179.

# APPENDIX A

**Sample size estimation**

Using a Pearson moment correlation, and with an alpha level of significance of 0.05, and power of 80% we estimated a correlation of (r) 0.4-0.6 between each of the NIRS measurements and the absolute holding time on the Sorenson test.

The sample size was calculated using the formula:

$\Delta = (\rho - \rho 0) / (1 - \rho\rho 0)$

$\mathbf{n} = \nu + 2$

Substituting the value of $\rho$ as 0.4 and $\rho 0$ as 0, $\Delta = 0.4$ referring to the power table for 5% level and a one tailed test with a power of 80% the value of $\nu$ is 36. Hence $n = \nu + 2$ i.e., 38 subjects (Appendix H).

$\rho$-Estimate of the correlation that is important to find (0.4-0.6)

$\rho\mathbf{0}$-Value of the null hypothesis (0)

$\Delta$- the critical effect size (a measure of how strong the theory should be to be important to society)

$\nu$- corresponds to the sample size in ways determined by the study design, but does not involve a population parameter

**n**- number of subjects

According to the above variables and referring to the power table (Kramer and Thieman, 1987) the sample size was estimated to be about 38 subjects.

## APPENDIX B

# Physical Activity Readiness Questionnaire:

# PAR-Q

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**Note: the PAR-Q must be completed before you can move on to the next assessment.**

Regular physical activity is fun and healthy, and increasingly more people are choosing to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor first.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

| YES | NO | | Have you experienced back pain in the past 3 months? |
|---|---|---|---|
| ○ | ◉ | 1. | Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor? |
| ○ | ○ | 2. | Do you feel pain in your chest when you do physical activity? |
| ○ | ○ | 3. | In the past month, have you had chest pain when you were not doing physical activity? |
| ○ | ○ | 4. | Do you lose your balance because of dizziness or do you ever lose consciousness? |
| ○ | ○ | 5. | Do you have a bone or joint problem that could be made made worse by a change in your physical activity? |
| ○ | ○ | 6. | Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition? |
| ○ | ○ | 7. | Do you know of any other reason why you should not do physical activity? |

# If you answered ...

## YES to one or more questions

Consult with your doctor BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want -- as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

## NO to all questions

If you answered NO to all PAR-Q questions, you can be reasonably sure that you can:

- Start becoming much more physically active -- begin slowly and build up gradually. This is the safest and easiest way to go.
- Take part in a fitness appraisal -- this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

**DELAY BECOMING MUCH MORE ACTIVE:**

- If you are not feeling well because of a temporary illness such as a cold or a fever -- wait until you feel better; or
- If you are or may be pregnant -- talk to your doctor before you start becoming more active.

# APPENDIX C
## INFORMATION LETTER

**Project Title**

Muscle deoxygenation as a determinant of Static Back Muscle Endurance.

**Investigators**

•Geetanjali Kashyap- Currently enrolled in MSc. in Physical Therapy at the University of Alberta.
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•Dr Michele Crites Battie- PhD, Professor in the Department of Physical Therapy, University of Alberta.

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•Dr Yagesh Bhambhani- PhD, Professor in the Department of Occupational therapy, University of Alberta.
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**Purpose**

The goal of the study is to better understand factors that affect the static endurance of the back muscle. In particular, we are looking at oxygen content of the back muscle while static work is being performed.

**Back ground**

Static back muscle endurance as measured by the Sorensen test is associated with the first time occurrence of low back pain. The performance on this test varies between people with and without back problems, because people with back problems perform poorly on the test. It has thus been used as a measure of physical performance among subjects and also has been used in many exercises to improve the endurance of the back muscles.

There is wide difference found in holding time during the performance of this test, ranging from 10 seconds to over several minutes. It is important to understand what factors are responsible for this variability in holding time. So far, age, gender, amount of fat, activity level, muscle size, family and childhood background have found to influence static back muscle endurance. Yet, much of the variation in the test performance remains unexplained. In this study we are going to examine the influence of oxygen use in the muscle.

**Study Requirements**

You will be required to attend just one test session and the test procedure will take about 15-20 minutes. All subjects will be healthy males. You should not have had any back problems (in the past 3 months), or any previous back surgery, heart or circulatory problems, neurological conditions or respiratory disease. If you have any of the above-mentioned problems please inform the investigator before the test begins.

**Test Procedure**

On the day of the test you will have the opportunity to ask questions about the study. If you choose to participate you will sign a form giving your consent and complete a brief health survey. Then the investigator will measure your height, weight and percentage of body fat. You should bring gym type shorts to wear during testing. You will be asked to remove your shirt and then bend over so that the investigator can locate the hipbone and trace the spot on your back where the sensors need to be attached. After that the light sensors will be attached on the right side of the back muscles with an elastic band. After this the NIRS unit, (which measures the oxygen content in the muscle) will be switched on. You might feel slight warmth because of the light from the sensors. NIRS uses light rays; there is no radiation involved. Please inform the investigator of any undue

discomfort immediately. You will be asked to lie down on a couch for two minutes. Then you will be asked to move your trunk to the edge of the couch to prepare to begin for the endurance test. You will rest your hands on a small stool for support, while straps are placed at the hips and the ankles to provide support. You will be asked to extend your trunk with hands across your chest and maintain this position for as long as possible.

You can end the test whenever you feel too tired or that the position is too uncomfortable to maintain. After which you will be given a four-minute rest. The investigator will ask a reason for terminating the test. This will conclude the test procedure.

**Benefits**

The study will lead to a better understanding of the physiological aspects that govern the back muscle endurance capacity. As a participant you will find out about the endurance of your back muscles.

**Risks**

This test does not have any long-term problem. You may feel some discomfort or exhaustion of the back or the legs due to fatigue. This is quite common after any physical activity or maximal exertion. NIRS has no known risks with the exception of possible redness (sunburn) that can occur on a very fair skin. Appropriate adjustment of the light intensity will avoid this.

**Confidentiality**

All information will be kept confidential. No one other than the investigators involved in this study will have access to subject's information. All data collection forms will be numbered and this number will then be put beside the subject's name on a master list. The data will be kept for 5 years after the study has been completed and will be secure in a in a filing cabinet in the Spinal Disorders Research unit at the University of Alberta. The names of the subjects will not appear in publication resulting from the research.

**Freedom to withdraw**

You have the right to refuse from participating in the study and also from answering any question asked by the investigator. There will be no penalty for withdrawing from the

study.

**Additional Information**

If at any time you wish to comment on this research project to an individual who is not involved in the study, you may contact Dr. Paul Hagler @ 492-9674. You may also contact the investigators at any time.

Research Participant _____

Date_____

Witness_____

## APPENDIX D

### SUBJECT DATA COLLECTION FORM

**Title:** Muscle Deoxygenation as a Determinant of Static Back Muscle Endurance

**Principal Investigator:**

Geetanjali Kashyap
Enrolled in Dept. Of Physical Therapy,
Faculty of Rehabilitation Medicine,
University of Alberta,
Edmonton, Canada
T6G2C5.

Contact : 439-0951.
E-mail : gkashyap@ualberta.ca

**For subject completion:**

Date:

1. Subject no_____
2. Age_____

3. Height: _____ Weight : _____ Body mass Index: _____

Percentage of body fat: 1)_____
2)_____ Average percentage of body fat_____
3)_____

Level of physical activity: Vigorous exercise for thirty minutes three times a week
Vigorous exercise of less than thirty minutes three times a week

4.Contact telephone no. (Residence)_____
(Off)_____

E-mail address_____

5.Current health status:

a. Cardiovascular problem_____

b. Neurological problem _____

c. Low back pain (3 months prior lasting for more than a day from the day of the test)

Daily_____

Not daily but once a week _____

Not weekly, but atleast once a month _____

Several times a year _____

2-3 times a year _____

Once a year _____

None at all _____

d. Upper or mid back pain

Daily_____

Not daily but once a week _____

Not weekly, but atleast once a month _____

Several times a year _____

2-3 times a year _____

Once a year _____

None at all_____

e. When was the previous attack of the pain? _____

f. Any contraindications to exercise (hypertension, myocardial infarction, cerebro vascular disease, respiratory disease) _____

g. Any medications (NSAIDS, Analgesics) _____

6. The length of time the test position is held (seconds)_____

7. How hard were you working? (0- no exertion and 10 almost maximal exertion)

Borg Scale of (0-10)_____

8. The reason for termination of the test- fatigue in_____

Back pain_____

Discomfort in the thighs or legs _____

Other reason_____

9. NIRS measurements

a. Magnitude of the initial deoxygenation (B)_____

b. Rate of initial deoxygenation (C)_____

c. Change in oxygenation at test termination (D) _____

d. Minimum change in blood volume (E) _____

e. Maximum change in blood volume (F) _____

f. Change in blood volume at test termination (G)_____

## APPENDIX E

## CONSENT FORM

**Part 1:** (to be completed by the principal investigator)

**Title of the Project:**

Muscle deoxygenation as a determinant of Static Back Muscle Endurance

**Researcher Information:**

Name of the principal investigator: Geetanjali Kashyap.
Affiliation: Enrolled in MSC Physical therapy at the University Of Alberta.
Contact Information: #9106, 3A, 112 street, Hub Mall
University of Alberta, Edmonton,
Canada, T6G2C5.
Phone no: (780) 439 0951.
e-mail : gkashyap@ualberta.ca

Name of the Co-investigator/ Supervisor: Dr.Michele Crites Battie.
Contact Information: University of Alberta, Physical therapy Department.
Telephone no: 492-5968
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Dr. Yagesh Bhambhani
Department of Occupational Therapy, University of Alberta.
Telephone no: (780) 492 7248
Fax: (780) 492 1626
E-mail: Yagesh.Bhambhani@ualberta.ca

**Part 2**: (to be completed by the subject)

Do you understand that you have been asked to be in a research study? Yes/No

Have you read and received a copy of the attached information sheet? Yes/ No.

Have you had an opportunity to ask questions and discuss the study? Yes/ No.

Do you understand that you are free to refuse to participate or withdraw from the study anytime? You do not have to give a reason. Yes/ No

Has the issue of confidentiality been explained to you? Do you understand who will access to your records/information? Yes/ No

Do you understand the benefits and risks involved in taking part in this research study? Yes/ No

**Part 3: Signatures.**

This study was explained to me by: Geetanjali Kashyap.
Date: _____
(I agree to take part in this study)

Signature of the Research participant: _____

Printed Name: _____

_____

Witness (if available): _____
Printed name: _____

_____

I believe that the person signing this form understands what is involved and voluntarily agrees to participate.

Researcher: _____
Printed name: _____
Date:_____

THE INFORMATION SHEET MUST BE ATTACHED TO THIS CONSENT FORM AND A COPY GIVEN TO THE RESEARCH SUBJECT.

## APPENDIX F

**Instructions for the Sorensen test**

**(instructions once the person has the sensors attached and in standing)**

You are going to lie face down on the plinth for 2 minutes.

After which you will move out of the plinth till the bony prominences on the front of your hip is at the edge of the bed (point to the anterior superior iliac spine) and your body will rest on a stool.

At my prompt you will extend your back with hands across your chest and hold the position for as long as possible trying to maintain contact with the sac hanging from the ceiling at all times. There will be no conversation once the test starts, except that I will occasionally give you feedback regarding your position. You have full control over when you want to stop the test. Once the test terminates you will lie on the couch for four minutes of rest.

After this I will ask you to rate how hard you worked and tell me why did you terminate the test?

# APPENDIX G

Master table 5%level (Kraemer H and Thiemann S, 1987)

| Delta | MASTER TABLE | | 5% Level, one tailed test | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 99 | 95 | 90 | 80 | 70 | 60 | 50 | 40 | 30 | 20 | 10 |
| 0.22 | 317 | 218 | 173 | 125 | 96 | 74 | 56 | 40 | 27 | 15 | . |
| 0.24 | 265 | 182 | 144 | 105 | 80 | 62 | 47 | 34 | 23 | 12 | . |
| 0.26 | 224 | 154 | 122 | 89 | 68 | 52 | 40 | 29 | 19 | 11 | . |
| 0.28 | 192 | 132 | 105 | 76 | 58 | 45 | 34 | 25 | 17 | 10 | . |
| 0.3 | 166 | 114 | 91 | 66 | 51 | 39 | 30 | 22 | 15 | . | . |
| 0.32 | 145 | 100 | 79 | 58 | 44 | 34 | 26 | 19 | 13 | . | . |
| 0.34 | 127 | 88 | 70 | 51 | 39 | 30 | 23 | 17 | 12 | . | . |
| 0.36 | 113 | 78 | 62 | 45 | 35 | 27 | 20 | 15 | 10 | . | . |
| 0.38 | 100 | 69 | 55 | 40 | 31 | 24 | 18 | 14 | . | . | . |
| 0.4 | 89 | 62 | 49 | 36 | 328 | 21 | 16 | 12 | . | . | . |
| 0.45 | 69 | 48 | 38 | 28 | 22 | 17 | 13 | 10 | . | . | . |
| 0.5 | 54 | 37 | 30 | 22 | 17 | 13 | 10 | . | . | . | . |
| 0.55 | 43 | 30 | 24 | 17 | 14 | 11 | . | . | . | . | . |
| 0.6 | 34 | 24 | 19 | 14 | 12 | . | . | . | . | . | . |
| 0.65 | 28 | 19 | 16 | 12 | 10 | . | . | . | . | . | . |
| 0.7 | 23 | 16 | 13 | 10 | . | . | . | . | . | . | . |
| 0.75 | 18 | 13 | 10 | . | . | . | . | . | . | . | . |
| 0.8 | 15 | 10 | . | . | . | . | . | . | . | . | . |
| 0.85 | 12 | . | . | . | . | . | . | . | . | . | . |
| 0 9 | . | . | . | . | . | . | . | . | . | . | . |